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BRANZ REPORT

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Comparative Cost Benefit Study of Energy Efficiency Measures for BCA Class 1 Buildings

Nigel Isaacs & Ian Page – BRANZ
Trevor Lee & David McCook – Energy Partners
David Wallace & Eric Sin - Northcroft (Australia)

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Executive Summary

Introduction

The results of this study are designed to articulate, quantitatively and concisely, the relative costs and benefits for building fabric related energy performance of BCA Class 1 buildings, through the:

- development of an economic analysis tool able to be used to estimate the relative cost-effectiveness of alternative scenarios under a range of conditions by determining the Net Present Value (NPV) of modelled, comfort-related, operational energy costs of representative building designs in various climate zones.
- preparation of modelled, comfort-related, operational energy costs of those representative buildings, based on variations in the thermal performance of the building fabric through combinations of floor, wall, ceiling, and roof insulation, wall and floor materials, various glazing options including glazing area, and window shading solutions. In addition the evaluation includes the energy and greenhouse savings, the costs of the measures, and the value of the energy saved.
- preparation of a report that summarises the results of options modelled and analysed.

A group of six representative houses was selected, modelled in NatHERS along with a range of energy efficiency alternatives, and the energy benefits converted to a cost for comparison with the cost of the energy efficiency alternative. The data generated by the study takes the form of energy use results from the modelling, energy costs from a survey of energy providers, and energy efficiency costs from Quantity Surveyors.

In conjunction with the analysis tool, this report should enable to interested reader to explore a wide range of possible energy efficiency alternatives, whether for their own home or use in the future development of energy efficiency requirements for the BCA. Once the BCA minimum performance requirements have been established, the financial analysis tool will provide interested users with the ability to explore the costs and benefits from exceeding these performance requirements, or to develop knowledge which may assist them in meeting their specific goals.

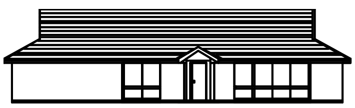
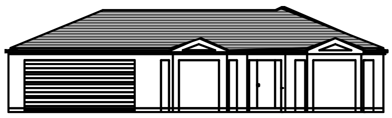
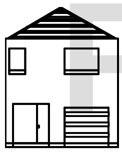
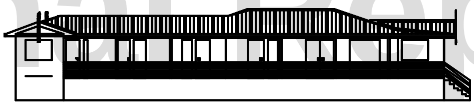
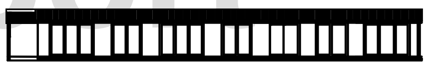
House Selection

The house design selection process built on analysis of size and type distribution from detailed analysis of 240 Victorian houses approved for construction in 1998-9 and 688 detached and 209 attached ACT dwellings approved between June 1998 and December 1999, coupled with analysis of Australian Bureau of Statistics Data on new housing throughout Australia. A range of 17 house designs were considered, and the following six house designs were selected for use in the simulation modelling:

1. **Detached House – Industry Example, Thermally Understood – Small Single Storey:** Previously used as the base case house by SEAV in developing its house energy rating software FirstRate.
2. **Detached House – Medium Single Storey:** Selected as very close in floor area to the 50th percentile in the set of houses studied in the Victorian housing study. Typical of the average project home built in recent years.

3. **Detached House –Large Two Storey, Attached Garage:** Selected as being very close in floor area to the 75th percentile in the set of houses studied in the Victorian housing study. Typical of the large 2 storey project home built in recent years.
4. **Townhouse – Two-storey, Two Neighbours, Attached Garage:** Selected from the Victorian sample as representative of very low surface area exposed to the weather and hence a relatively low sensitivity to the benefits of wall insulation.
5. **Detached House - High Ventilation Design:** An archetypical "Humid Tropical" house with long plan form, cross flow ventilation and elevated construction.
6. **Detached House - Passive Solar Design:** Selected as reasonably thermally efficient, sensitive to orientation,.

Summary Figure 1 provides illustrations of the six houses along with Gross Floor Area (includes garage, etc) and Conditioned Floor Area.

		
House 1: Small Single Storey (173 m² GFA, 143 m² CFA)	House 2: Medium Single Storey (251 m² GFA, 168 m² CFA)	House 3: Large Two Storey (294 m² GFA, 203 m² CFA)
		
House 4: Townhouse (133 m² GFA, 84 m² CFA)	House 5: Cross Ventilated Tropics (156 m² GFA, 138 m² CFA)	House 6; "Passive Solar" (172 m² GFA, 152m² CFA)

Summary Figure 1: House Designs

Key Variables

- **Energy Types & Costs**: Unit costs for electricity and natural gas were obtained for each of the climate locations.

- **CO_2 Intensity Factors** are based on data from the 1999 "National Greenhouse Gas Inventory" for natural gas and the marginal emissions factors for electricity from the AGO "Greenhouse Gas Abatement Program" (GGAP)

- **Lifestyle Variables**: The standard NatHERS conditioning (heating and/or cooling as appropriate to the location) regime (conditioning 7 am to 12 pm – 17 hours conditioning), and a morning/evening conditioning (morning 7 am to 9 am and evening 5 pm to 11 pm – 8 hours conditioning) were run for all house variations in all locations. In both cases, the thermostat settings included in NatHERS for the relevant climate were used.

- **Climate Locations**: Twelve locations (listed in Summary Table 1) provide representative examples of each of the State or Territory capital cities and the range of climate zones likely to be found over Australia.

#	Location	Climate Zones	NatHERS Zone Number
1	Darwin, NT	Hot humid summer – warm winter	1
2	Longreach, QLD	Hot dry summer – warm winter	3
3	Townsville, QLD	Hot humid summer – warm winter	5
4	Brisbane, QLD	Warm humid summer – mild winter	10
5	Perth, WA	Warm temperate	13
6	Sydney, NSW	Warm temperate	17
7	West Sydney, NSW	Mild temperate	28
8	Mildura, VIC	Hot dry – cool winter	27
9	Adelaide, SA	Mild temperate	16
10	Melbourne, VIC	Mild temperate	21
11	Canberra, ACT	Cool temperate	24
12	Hobart, TAS	Cool temperate	26

Summary Table 1: Study Climate Zones

- **Costing Locations**: Summary Table 2 provides the comparison of costs for the twelve selected locations, based on unity for the highlighted state or territory capital city. It can be seen that the variations in costs is from 0.94 (i.e. 6% less) in Hobart to 1.28 (i.e. 28% more) in Darwin

	Location	Cost Ratio
	NEW SOUTH WALES & ACT	
1	Sydney	1.00
2	West Sydney	1.00
3	Canberra	1.02
	VICTORIA & TASMANIA	
4	Melbourne	1.00
5	Mildura	1.02
6	Hobart	0.94
	QUEENSLAND	
7	Brisbane	1.00
8	Townsville	0.99
9	Longreach	1.15
	WESTERN AUSTRALIA	
10	Perth	1.00
	SOUTH AUSTRALIA & NT	
11	Adelaide	1.00
12	Darwin	1.28

Summary Table 2: Regional Pricing Variations

- **Economic Variables**: The Net Present Value (NPV) analysis involves a number of variables including costs of measures undertaken to improve energy efficiency, discount rate, building life, energy price, the quantity and type of energy saved, and the perspective from which savings are considered – the dwelling occupant or society. The default discount rate has been set at 5% in the analysis tool, and the default analysis period set to 40 years, as intermediate value. All defaults can be altered by the user, as required.

  It should be noted that the financial analysis omits some costs that would be included in a full economic analysis, such as: reduced appliance capital and maintenance costs due to energy efficiency; multiple benefits of energy efficiency options such as the weathertightness benefits of eaves and verandahs; health benefits due to warmer (or in hot climates, cooler) indoor temperatures; or moisture control due to higher surface temperatures in cool locations which reduce opportunities for mould and other moisture related problems

- **Energy Efficiency Variations**: Variation of the thermal performance of the building fabric was achieved through combinations of floor, wall, ceiling, and roof insulation, wall and floor materials (including brick & concrete walls, suspended and slab-on-ground floors as appropriate for the region), various glazing options including glazing area, and window shading solutions. Summary Table 3 lists the different wall, roof, floor (suspended and slab-on-grade), glazing and shading energy efficiency options that were investigated.

Efficiency Case	1	2	3	4	5
Wall constructions	**A** Weatherboard	**B** Brick Veneer	**C** Cavity Brick	**D** Concrete Block	
Wall Insulation Type 1	Reflective Foil	Reflective foil	30mm Polystyrene	28mm Polystyrene	
Wall Insulation Type 2	R1.5 fibreglass	R2 fibreglass	40mm Polystyrene	38mm Polystyrene	
Wall Insulation Type 3	R2 fibreglass	R2 fibreglass + foil	50mm Polystyrene	47mm Polystyrene	
Roof	Foil under tiles.	R1 Ceiling	R3 Ceiling	R5 Ceiling	Foil + R3 Ceiling
Suspended floor	Dropped foil	R2 fibreglass			
Slab-on-grade floor	25mm Polystyrene to 450mm depth				
Glazing **NatHERS code** **Frame Type**	Single clear 6mm (SG Clr) Aluminium	Single tinted 6mm (SG Tint) Aluminium	Double Clear (DG Clr 4/8/4) Thermally broken	Double Low-E (DG,LE,HI) Thermally broken	
Shading	No Eaves	600mm Eaves)	Fabric awnings	3.6m Verandah	

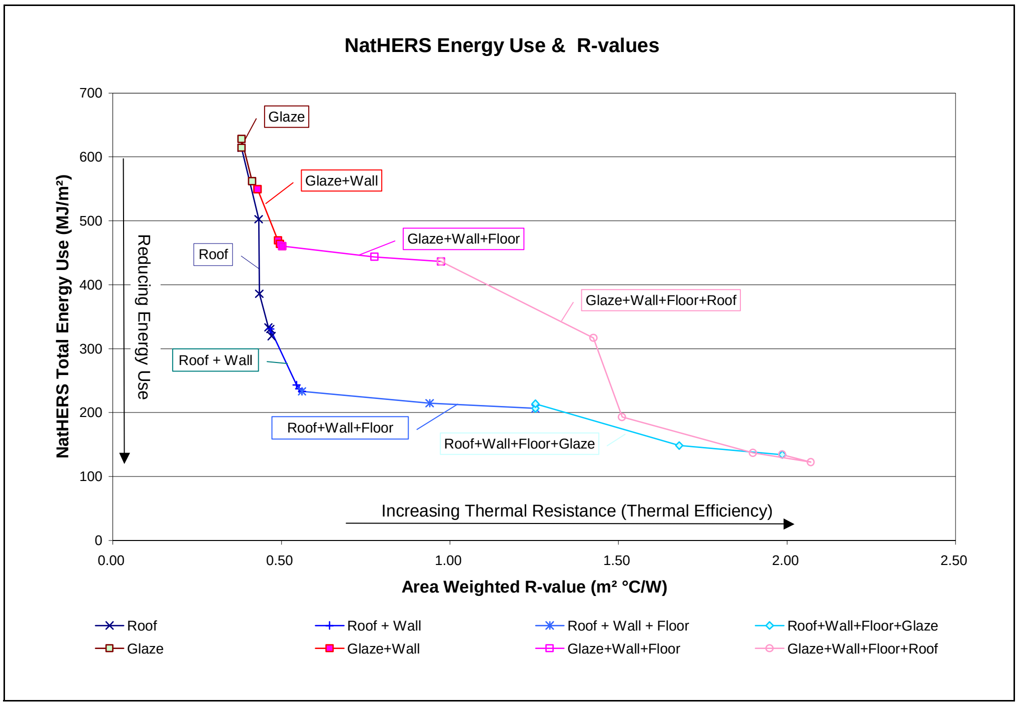
Summary Table 3: Construction Brief Descriptions

Energy Modelling

The majority of modelling for this study was undertaken using NatHERS. NatHERS is a house energy performance modelling software tool built around the CHENATH modelling engine, both of which were developed by CSIRO, Division of Building, Construction and Engineering. NatHERS provides an estimate of the energy needed to keep a dwelling thermally comfortable (heating and cooling) in a given location, and also provides a rating between 0 and 5 Stars. No allowance is made for appliance efficiency. The house is assumed to be operated under a standard occupancy schedule appropriate for the given location. Therefore the rating is not designed to predict the energy demand of a particular family, but instead provides an accurate comparison of building performance on the basis of standardised criteria and hourly weather data. Of particular importance is that all houses are correctly operated to achieve comfort conditions appropriate to the local climate, thus permitting direct comparison.

Additional NatHERS sensitivity studies have been undertaken to investigate the importance of glazing area, the occupancy schedule, the use of curtains and blinds, the use of carpet, natural ventilation and infiltration. A separate investigation has been undertaken into issues of thermal insulation in tropic climates where air conditioning is not used.

It is not possible to simply add the energy benefits of different energy efficiency options, as one option may interact with another. Summary Figure 2 provides an example illustrating how the order of adding the different energy efficiency options can result in different energy benefits, even though the end result when all the options are put in place is the same whichever path has been chosen. It is thus necessary to model each of the various combinations, and then select the optimum results based on either the improvement in energy efficiency, the reduction in greenhouse gas emissions, the financial optimal solution or the lowest capital investment – or any other selection criteria.

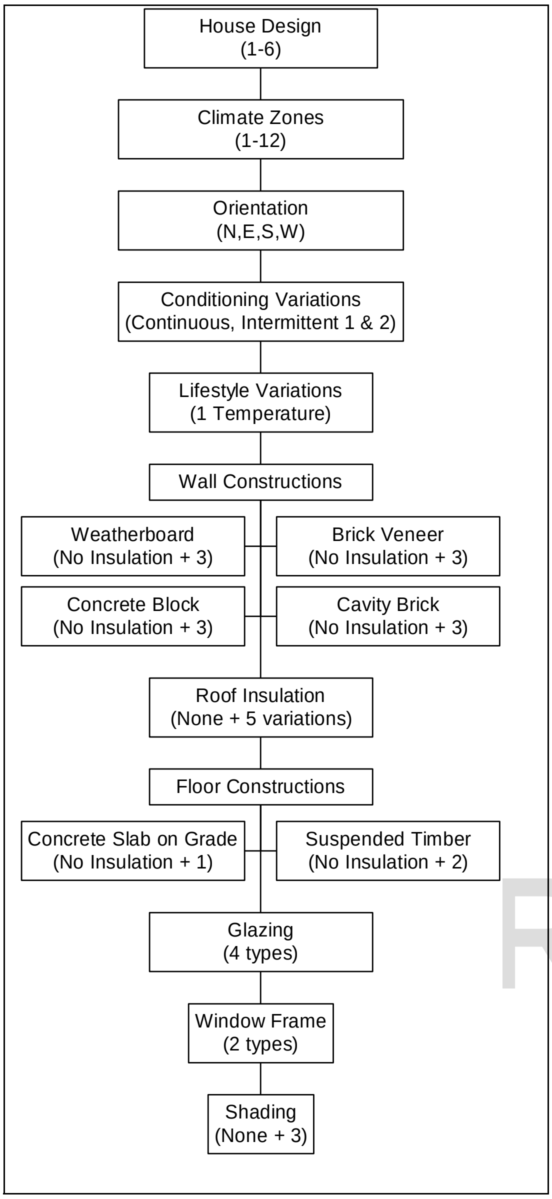


Summary Figure 2: Energy Consequences of Increasing Component R-values

In addition a limited number of model runs using simulation programmes EnCom2 and DOE2 were commissioned for comparison purposes both for the main study, and to support the Regulatory Impact Statement for the inclusion of interim roof insulation in the BCA from January 2002.

Financial Analysis Tool

The financial modelling tool runs in Excel 2000 under Windows. The programme obtains data from an MS Access dataset. The data includes all insulation combinations for six houses in 12 climate zones, with both 17 hours and 8 hours of conditioning. The programme file size is approximately 3.6 MB, and the Access dataset 36 MB in size. Once 'zipped', the files reduce to approximately 3.1 MB and 16 MB respectively. On a 500MHz PC, with 128MB RAM, the file takes about 30 seconds to load, and once loaded the menu selections appear with a delay of a few seconds. (Note however the operation which calculates insulation combinations ("Max Star Rating") for all climate zones, takes about 3½ minutes to run.). Additional memory, or a faster computer, will further speed the analysis.



Summary Figure 3: Modelling Variations

For each combination of:

- house type (6 types),
- climate zones (12 types),
- orientation (4 types),
- wall type(4 types),
- glazing (4 types), and
- shading (4 types)

the analysis tool provides data on the:

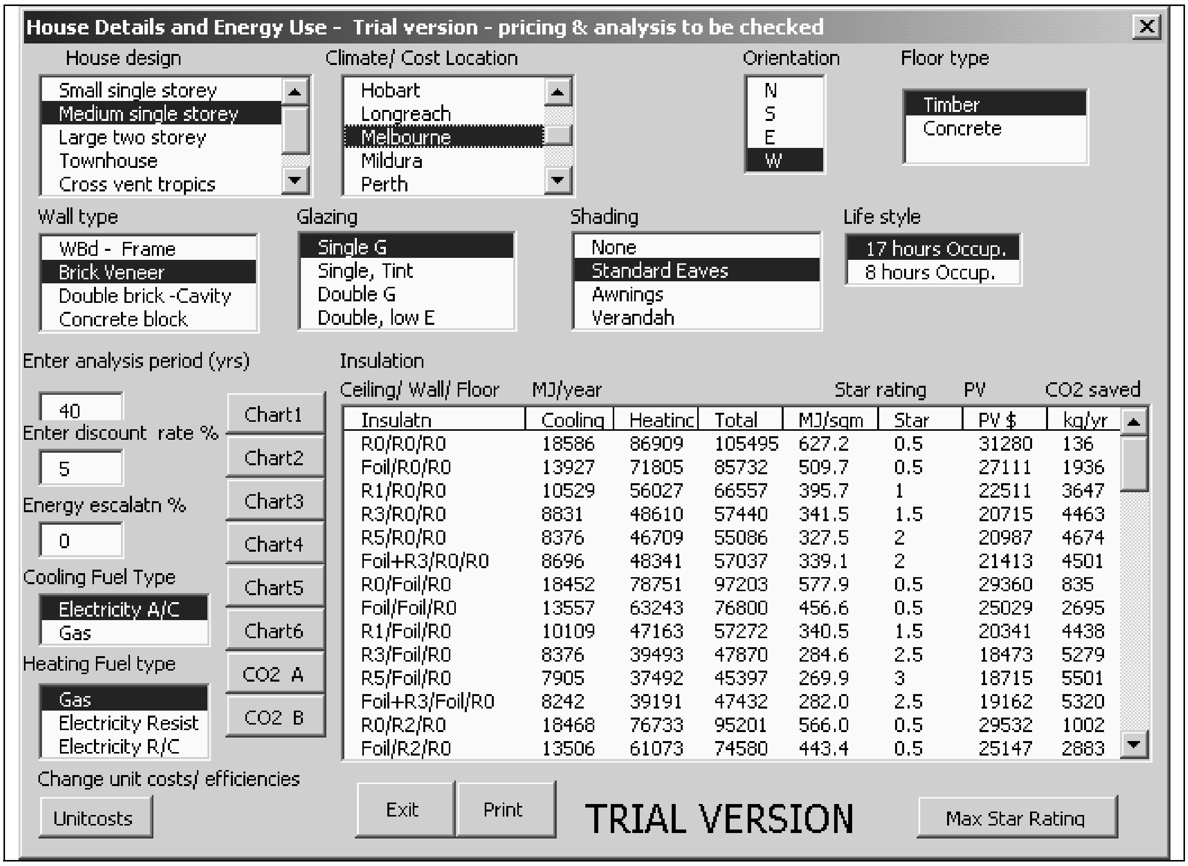
- energy consumption,
- present value and
- CO_2 saved

for 72 timber floor combinations of insulation, and 48 concrete floor combinations of insulation. This gave a total of 4,423,680 model runs, or 61,440 for each house in each location.

The first screen of the tool (Summary Figure 4) permits the user to select from look-up windows the variables given Summary Figure 3, to select the cooling and heating fuel types, and to enter the analysis period, the discount rate and the energy escalation rate. The analysis tool calculates the present value of insulation costs plus discounted energy costs.

Should the user wish, a second screen provides access to alter the appliance energy efficiencies, replacement periods for double glazing and awnings, changes in the costs for glazing types; shading types and energy, as well as the carbon intensity for electricity.

The third tool screen provides a calculation of the NPV for each house type over all locations and floor types, with a selection based on the closeness to the maximum NPV and the desired NatHERS Star rating. Analysis has found that the NPV curves for energy efficiency alternatives tend to be very shallow – a small change in the NPV could result in a wide range of alternative energy efficiency options becoming ‘best’ choice.



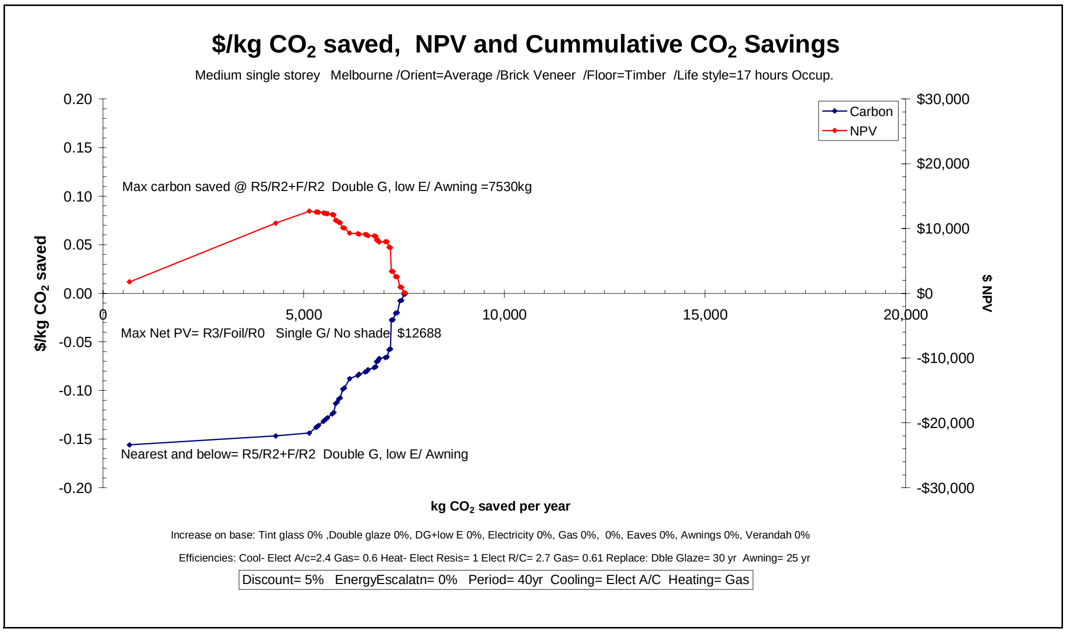
Summary Figure 4: Financial Analysis Tool Data Entry - Screen 1

Eight charts are available from the financial analysis tool:

1. Present Value (PV) for each combination of insulation for a given house, location and construction
2. PV against envelope area-weighted R-value
3. Net Present Value (NPV) for each insulation combination (NPV based on nil insulation, plain glazing and no shading as the base case)
4. NPV against envelope area-weighted R-value
5. NPV against energy consumption per unit floor area for all insulation combinations
6. Minimum PV for each orientation of the house against the area-weighted R-value.
7. CO_2 savings supply curve (see Summary Figure 5)
8. Energy savings supply curve (see Summary Figure 6)

Two graphs provide an overview of the cost of CO_2 savings compared to the NPV, total CO_2 saved and total energy saved per year.

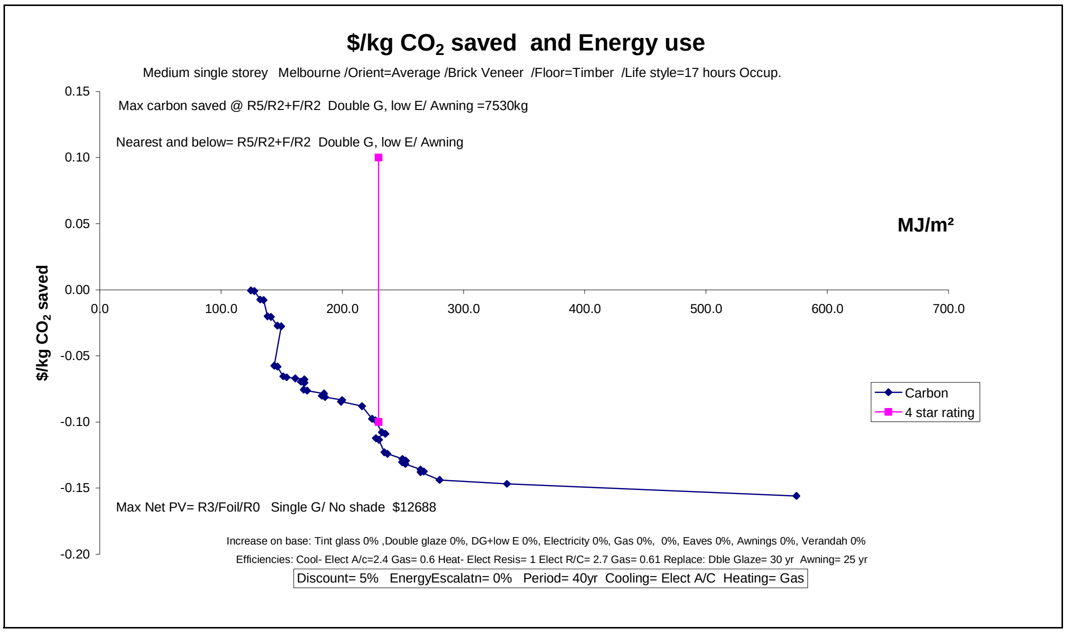
CO_2 A: $CO_{2\ savings}$ supply curve (Summary Figure 5): Two lines are shown on this chart. The lower line is the $ per kg of CO_2 saved for “outer envelope” combinations of insulation. This is the so called “CO_2 supply” line. The $ amount is the Net Present Value, with the base case as per Chart 5. The calculation of CO_2 savings is the average of four orientations with nil insulation, single glazing, and no shade as the base case. The CO_2 saved line is below the x-axis for each insulation combination that has a positive NPV. Above the x-axis cost of the insulation exceeds the discounted value of the energy savings and there is a net cost to save additional CO_2.



Summary Figure 5: Example of Chart CO_2 A

CO_2 B: Energy savings supply curve (Summary Figure 6): This shows the CO_2 supply line from the previous chart, with the same insulation combinations and same vertical axis. But the x-axis is energy use, rather than CO_2 saved. The line may “fold-in” on itself in those locations where significant amounts of different fuel types are used for heating and cooling, e.g. Adelaide, Melbourne or Sydney. Points below the x axis and to the left of the four Star Rate line are combinations with positive NPV and very good energy performance. They can each be identified on the print-out (see in Summary Table 4). Note that in some cases there are no combinations of energy efficiency alternatives for a given house construction with both a positive NPV and a 4 Star (or better) NatHERS rating.

The ‘print’ output for either of the CO_2 charts gives details of all points on the CO_2 and NPV line, as illustrated in Summary Table 4 for the ‘Medium single storey’ house located in Melbourne with Brick Veneer walls, timber floor and the standard NatHERS occupancy schedule. the printout also gives a summary of the key assumptions (lifetime, energy types) and any modifications to the base costings.



Summary Figure 6: Example of Chart CO_2 B

Summary Table 4 provides the cost for the CO_2 savings (negative values indicate a cost benefit from the saving, positive values a costs to the user), the amount of CO_2 saved per year, the energy efficiency combination that achieves this (formatted as Roof / Wall / Floor insulation Window / Shading alternative), the Net Present Value of that combination, the capital investment required, and the energy use per square metre per year. It also provides information on the cost of the energy efficiency combination as a percent of the total cost of the house, and the proportion of the maximum CO_2 savings for that option compared to the CO_2 savings for the energy efficiency combination having closest to zero NPV.

In this case the combination closest to zero NPV has R-5 insulation in the ceiling, R 2 plus foil in the walls, R 2 under floor insulation, low-e double-glazed windows with awnings over all windows. This package of energy efficiency options costs 8% of the total cost of the house. The case with Maximum NPV has R 3 in the roof, foil in the walls and no insulation under the floor, single glazing and no shading. This package costs 0.8% of the total cost of the house, and saves 68% of the maximum CO_2 savings.

$/kg CO_{2saved}	CO_{2saved} kg/yr	Insulation Glaze/Shade		NPV $	Capital $	Energy MJ/m²	% Capital	% CO_2 savings
-0.1559	657	R0/Foil/R0	1/1	1758	159	574.5	0.1	8.7
-0.1468	4304	R1/Foil/R0	1/1	10839	1176	335.7	0.5	57.1
-0.1438	5143	R3/Foil/R0	1/1	12688	1671	280.2	0.8	68.3
-0.1378	5308	R3/Foil/Foil	1/1	12552	2459	264.7	1.1	70.4
-0.1374	5330	R3/R2/R0 1/1		12563	2345	267.2	1.1	70.7
-0.1359	5371	R3/R2+F/R0	1/1	12522	2504	264.4	1.1	71.3
-0.1317	5491	R3/R2/Foil	1/1	12412	3133	252.0	1.4	72.9
-0.1303	5530	R3/R2+F/Foil	1/1	12367	3292	249.3	1.5	73.4
-0.1293	5555	R5/R2/R0 1/1		12327	3209	252.4	1.5	73.7
-0.1280	5595	R5/R2+F/R0	1/1	12285	3368	249.6	1.5	74.3
-0.1241	5712	R5/R2/Foil	1/1	12168	3996	237.4	1.8	75.8
-0.1228	5752	R5/R2+F/Foil	1/1	12124	4155	234.7	1.9	76.3
-0.1134	5795	R5/R2/R2 1/1		11273	5190	230.3	2.4	76.9
-0.1121	5832	R5/R2+F/R2	1/1	11223	5349	227.7	2.4	77.4
-0.1089	5871	R5/R2/Foil	2/1	10970	5286	235.5	2.4	77.9
-0.1077	5912	R5/R2+F/Foil	2/1	10930	5445	232.7	2.5	78.5
-0.0987	5975	R5/R2/R2 2/1		10118	6480	227.4	2.9	79.3
-0.0976	6014	R5/R2+F/R2	2/1	10074	6639	224.6	3.0	79.8
-0.0879	6144	R3/Foil/R0	3/1	9267	6646	216.3	3.0	81.5
-0.0846	6345	R3/Foil/Foil	3/1	9208	7434	198.9	3.4	84.2
-0.0834	6382	R3/R2+F/R0	3/1	9129	7479	199.9	3.4	84.7
-0.0810	6535	R3/R2/Foil	3/1	9088	8108	185.8	3.7	86.7
-0.0802	6574	R3/R2+F/Foil	3/1	9044	8267	183.1	3.7	87.3
-0.0785	6606	R5/R2+F/R0	3/1	8893	8343	185.0	3.8	87.7
-0.0763	6757	R5/R2/Foil	3/1	8848	8972	171.1	4.1	89.7
-0.0755	6796	R5/R2+F/Foil	3/1	8805	9131	168	4.1	90.2
-0.0703	6814	R3/R2/Foil	4/1	8220	9398	169	4.3	90.4
-0.0695	6854	R3/R2+F/Foil	4/1	8179	9557	166	4.3	91.0
-0.0678	6868	R5/R2+F/R0	4/1	7990	9633	169	4.4	91.2
-0.0670	6882	R5/R2+F/R2	3/1	7912	10324	161	4.7	91.3
-0.0661	7035	R5/R2/Foil	4/1	7978	10262	154	4.7	93.4
-0.0654	7075	R5/R2+F/Foil	4/1	7938	10421	151	4.7	93.9
-0.0580	7126	R5/R2/R2 4/1		7097	11455	147	5.2	94.6
-0.0574	7164	R5/R2+F/R2	4/1	7052	11614	144	5.3	95.1
-0.0276	7184	R5/R2/Foil	4/2	3398	15038	150	6.8	95.3
-0.0271	7227	R5/R2+F/Foil	4/2	3365	15197	147	6.9	95.9
-0.0204	7292	R5/R2/R2 4/2		2559	16231	141	7.4	96.8
-0.0200	7333	R5/R2+F/R2	4/2	2522	16390	138	7.4	97.3
-0.0077	7400	R5/R2/Foil	4/3	980	16288	135	7.4	98.2
-0.0074	7441	R5/R2+F/Foil	4/3	940	16447	132	7.5	98.8
-0.0008	7496	R5/R2/R2 4/3		109	17482	127	7.9	99.5
-0.0005	7535	R5/R2+F/R2	4/3	65	17641	125	8.0	100.0

Summary Table 4: Example of $C0_2$ Results

Notes to Summary Table 4: (4 star rating in Melbourne = 230.0 MJ/m²)

- Based on: Medium single storey house, located in Melbourne with average orientation, Brick Veneer walls, timber suspended floor, 17 hours Occupancy.
- Efficiencies: Cooling- Electric air conditioning =240% Heat- Gas= 61%
- Replacements: Double Glazing after 30 years and Awning after 25 years

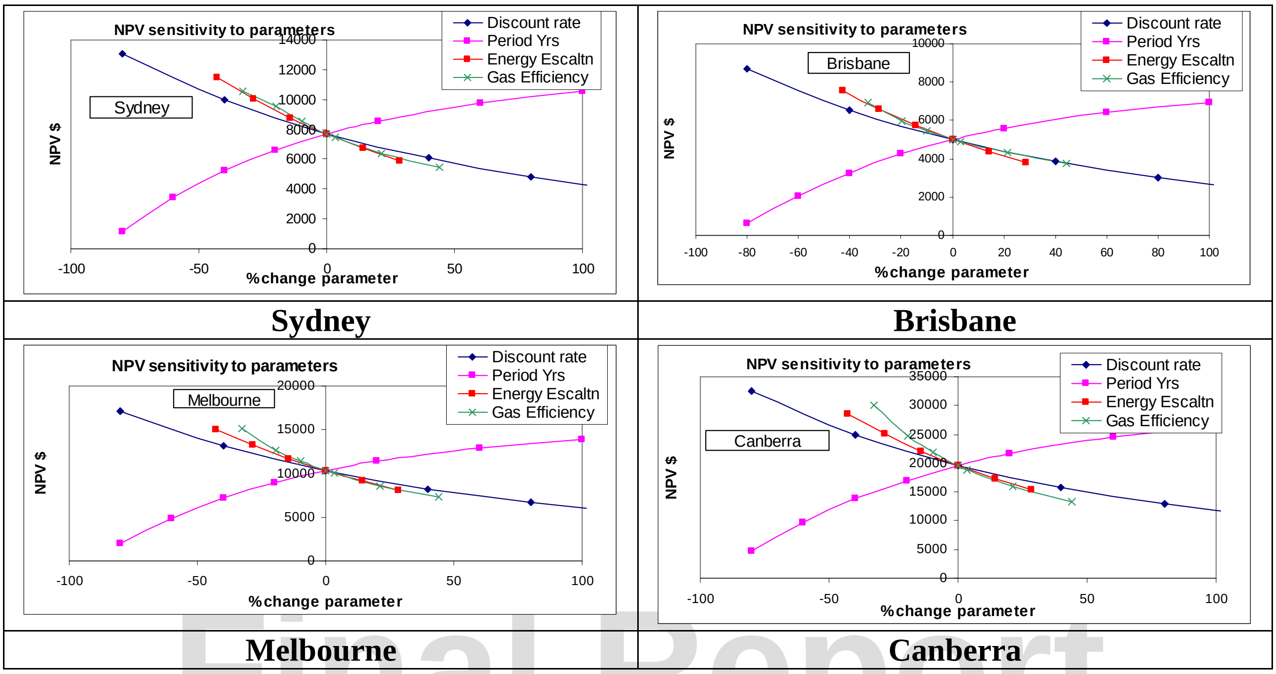
Financial Sensitivity Investigation

Summary Figure 7 shows selected sensitivity runs for the medium sized, single storey, brick veneer house on a concrete slab in four locations – Sydney, Brisbane, Melbourne and Canberra. The parameters changed were:

- Discount rates, from 1% to 11%, in 2% steps.
- Period of analysis from 5 to 70 years, in various steps.
- Energy escalation rate from –2% to + 3%.
- Gas heating efficiencies from 41% (1 AGA Star) to 88% (5 AGA Stars), in Star steps.

The charts show the change in maximum NPV due to variations in the selected parameters, varied one at a time from the base case. The base case is the insulation combination with maximum NPV, for 5% discount rate, 40 years analysis period, zero escalation in real energy costs, and 61% efficiency in gas heating appliances. The vertical axis is the NPV and the horizontal axis is percentage changes in the parameters.

For example a 70 year period is a 75% increase on the base case and in Sydney this causes the NPV to increase by about 15%. A discount rate of 9% is an 80% increase on the base case, ((9/5)-1)*100, and causes the NPV to reduce by about 44% in Sydney



Summary Figure 7: Sensitivity Of NPV To Changes In Various Parameters by Location

The steeper the curves the more sensitive the NPV is to changes in that parameter. The curves indicate the results are sensitive for the following changes:

- **Analysis years, at the shorter analysis periods**: However after about 40 years the curve becomes quite flat.
- **Gas appliance efficiencies in the cooler climates:** A change from a low star rating to higher ratings has a large influence in Canberra and Melbourne, and is not quite as “elastic” in Sydney and Brisbane.
- **Energy price escalation:** At 2% and 3% escalation the change to NPV is large in all locations. Note escalation increases are almost equivalent, in terms of the present value formula, to reducing the discount rate by the same amount.

Note that with all these changes the NPV remains positive, but in some cases the insulation combination to achieve the NPV changes. For example, in Canberra the combination reduces from R5/R2/R0 1/1 to R3/Foil/R0 1/1 for high discount rates (above 7%), low years of analysis (below 20 years), and high gas heater efficiencies (above 74%). In the other three locations the only change is for the 5 years analysis period, when the insulation combination with maximum NPV is R1/Foil/R0, down from R3/Foil/R0 for the base case. These are minor changes in the amount of insulation, and suggest that the maximum NPV insulation combinations are fairly insensitive to changes in these parameters. However other locations, and house types, would also need to be tested for sensitivity.

Conclusions and Recommendations

This work has developed a financial analysis tool and an associated database of space heating and cooling energy use which can be used to develop energy efficiency alternatives for Building Code of Australia Class 1 buildings.

A range of six houses has been selected, and model in the NatHERS programme for 12 locations around Australia. Each house has been modelled facing each of the four principal compass directions for four wall constructions (weatherboard, brick veneer, cavity brick and concrete block), two floor types (suspended and slab-on-grade) and two lifestyle occupancies. A range of energy efficiency improvements were modelled as applying to the roof, wall, floor, glazing and windows shading both individually and in combination. A total of approximately 4.4 million NatHERS runs were undertaken.

Each energy efficiency alternative was costed, and a location based pricing variation system developed. The pricing data and the results of the NatHERS model runs are available through the Financial Analysis Tool – an MS Excel 2000 spreadsheet with an associated MS Access database.

This report includes a limited number of results from the financial analysis tool. The tool is now available not only for use in the development of any future BCA energy efficiency requirements, but also to permit other interested stakeholders to explore their specific interests.

It was found that thermal insulation in tropical climate resulting in improved conditions whether air conditioning or ceiling fans were used, suggesting separate BCA requires would be unnecessary.

Issues identified for future consideration as part of the energy efficiency code development process include:

- Standard methods for determining and expressing R-values
- Mechanisms to permit the use of different thermal simulation programmes
- Methods to incorporate non-financial, and possibly non-energy, benefits of energy efficiency, specifically including comfort but there are a range of other issues e.g. eaves perform a critical role in maintaining the weather tight performance of a house, but in this analysis it has been assumed all the cost and all the benefit are solely energy related.
- Methods to allocate shifts in capital expenditure due to energy efficiency e.g. reducing the temperature in an uninsulated house will require a larger appliance than would be the case in an insulated houses
- Survey data to better characterise the ‘comfort’ and operating regime of occupants of the new houses to which future BCA energy efficiency requirements would apply.

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- **Ivan Donaldson** (Executive Director ABCB), supported by Jack Bramwell
- **Alan Pears** (Community Advocate)
- **Tony Marker** (Manager Energy Efficiency, AGO), supported by Stephen Berry

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SUSTAINABLE ENERGY AUTHORITY

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Target Audience

The target audience for the study is the Commonwealth Government, State and Territory Governments, ABCB, the building industry through appropriate industry consultative mechanisms, and the Australian community. It is expected that the report will ultimately be available to the general public as a joint ABCB/AGO publication.

The Executive Summary is intended for wider distribution.

Comparative Cost Benefit Study of Energy Efficiency Measures for BCA Class 1 Buildings

BRANZ Report UC0180/01

Nigel Isaacs & Ian Page – BRANZ
Trevor Lee & David McCook – Energy Partners, a division of Energy Strategies Pty Ltd
David Wallace & Eric Sin - Northcroft (Australia) Pty Ltd

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KEYWORDS

energy efficiency, building code, Australia, NatHERS, financial analysis, energy analysis, energy models

ABSTRACT

The report describes the selection of a group of six representative Australian houses, modelled in the thermal simulation programme NatHERS along with a range of energy efficiency alternatives, and the energy benefits converted to a cost for comparison with the cost of the energy efficiency alternative. The data generated by the study (energy use results from the modelling, energy costs from a survey of energy providers, and energy efficiency costs from Quantity Surveyors) has been used in an associated Excel 2000 financial analysis tool. The tool will be available to support the development of energy efficiency requirements for Class 1 buildings (principally stand alone houses and row houses) for the Building Code of Australia.

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1. INTRODUCTION

The results of this study are designed to articulate, quantitatively and concisely, the relative costs and benefits for building fabric related energy performance of BCA Class 1 buildings, through the:

- development of an economic analysis tool able to be used to estimate the relative cost-effectiveness of alternative scenarios under a range of conditions by determining the Net Present Value (NPV) of modelled comfort-related operational energy costs of representative building designs in various climate zones.

- preparation of modelled, comfort-related, operational energy costs of those representative buildings, based on variations in the thermal performance of the building fabric through combinations of floor, wall, ceiling, and roof insulation, wall and floor materials, various glazing options including glazing area, and window shading solutions. In addition the evaluation includes the energy and greenhouse savings, the costs of the measures, and the value of the energy saved.

- preparation of a report that summarises the results of options modelled and analysed.

A group of six representative houses was selected, modelled in NatHERS along with a range of energy efficiency alternatives, and the energy benefits converted to a cost for comparison with the cost of the energy efficiency alternative. The data generated by the study takes the form of energy use results from the modelling, energy costs from a survey of energy providers, and energy efficiency costs from Quantity Surveyors.

In conjunction with the analysis tool, this report should enable the interested reader to explore a wide range of possible energy efficiency alternatives, whether for their own home or use in the future development of energy efficiency requirements for the BCA. Once the BCA minimum performance requirements have been established, the financial analysis tool will provide interested users with the ability to explore the costs and benefits from exceeding these performance requirements, or to develop knowledge which may assist them in meeting their specific goals.

1.1 Project Outline

This project was to undertake an financial analysis of potential energy efficiency requirements under the BCA for Class 1 buildings. This has required a total of over four million NatHERS runs of the six house models covering the different energy efficiency alternatives and combination of alternatives, in a range of locations. This report provides a background to the process and the financial analysis tool developed by the project. Section 9 provides a summary of the contract requirements.

Figure 1 provides a diagrammatic outline of the process of the work covered in the project.

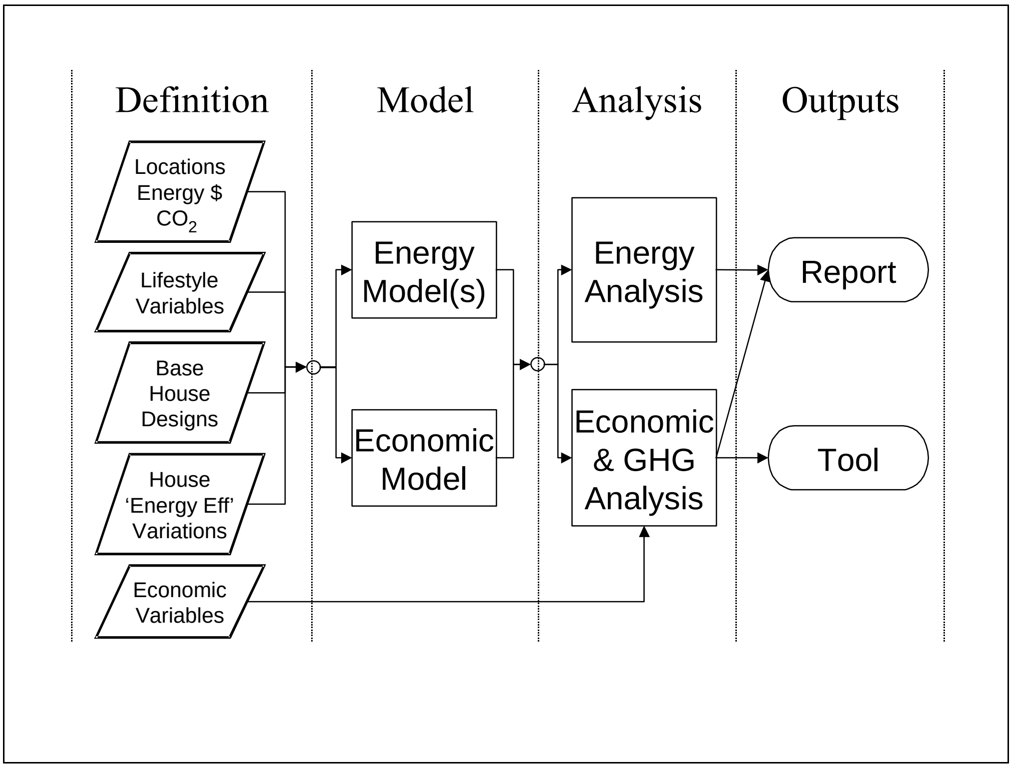


Figure 1: Work Activities

Table 1 outlines the work allocations between the contractor and main sub-contracting organisations.

Work Phase	BRANZ	Energy Partners	Northcroft
Project Management	Lead		
1. Definition			
• Locations	Assist	Lead	
• Energy Types & Costs		Lead	
• CO_2 factors		Lead	
• Lifestyle Variables	Assist	Lead	
• Base House Designs	Assist	Lead	Price
• Energy Efficiency Variations	Assist	Lead	Price
• Economic Variables	Lead	Assist	
2. NatHERS Energy Modelling	Assist	Lead	
3. Cost Analysis	Lead		
4. Financial Tool Development	Lead		
5. Financial Analysis	Lead		
6. Reporting	Lead	Assist	

Table 1: Work Allocation

The Sustainable Energy Authority of Victoria (SEAV) provided an in-kind contribution to the project by undertaking the very large number of NatHERS simulation runs.

Luminis Pty Ltd, the consulting arm of the University of Adelaide, undertook the EnCom2 energy model creation and simulation runs. Dr Steve Szokolay, University of Queensland, organised the DOE2 model creation and simulation runs.

Additional support was also provided for the regional costing variations by Cordell Construction Information Services Pty Ltd

The following text describes in more detail the main phases of the project, as listed in Table 1, as originally proposed and as finally completed. References are provided to tables, figures or text elsewhere in the report which more fully detail the results.

1.1.1 Definition Phase:

This phase collected and defined the variables for the energy, GHG and financial modelling:

- **Climate Locations**: It was originally proposed that six climate zones would be identified by the Study Committee for energy modelling. After discussions with the Study Committee it was agreed that the twelve locations, listed in Table 16 (page 22), would provide representative examples of each of the State or Territory capital cities and the range of climate zones selected for use in the overall project, as illustrated in Figure 6 (page 22).

- **Costing Locations**: The pricing for the various energy efficiency options and energy prices, was originally to be based on State and Territory capital cities (ACT, NSW, NT, QLD, SA, TAS, VIC, WA) plus no less than two regional centres in each of VIC, NSW and QLD for a total of 14 locations. Initial investigations by Northcrofts, supported by regional pricing analysis from Cordells resulted in the eleven locations listed in Table 13 (page 19).

- **Energy Types & Costs**: Unit costs for electricity (Table 17, page 24) and natural gas (Table 18, page 24) were obtained for each of the climate locations.

- **CO_2 Intensity Factors:** Australia's State and Territory Greenhouse Gas Inventories 1990 and 1995 were published in August 1998 and are available for NSW, ACT, TAS, WA, SA, Vic, QLD and NT. The appropriate State or Territory value have been used for the calculation of GHG emissions in the location for natural gas and electricity (Table 19, page25).

- **Lifestyle Variables**: The standard NatHERS conditioning (heating and/or cooling as appropriate to the location) regime (conditioning 7 am to 12 pm – 17 hours conditioning), and a morning/evening conditioning (morning 7 am to 9 am and evening 5 pm to 11 pm – 8 hours conditioning) were run for all house variations in all locations. In both cases, the thermostat settings included in NatHERS for the relevant climate were used.

- **Base House Designs**: A range of possible house designs were discussed with the Study Committee, and six were selected. Section 2 provides details of the selection methodology, and the final house designs. Section 11 provides statistical data used in the selection of the house designs, and provides plan drawings of the six final house designs.

- **Energy Efficiency Variations**: Variation of the thermal performance of the building fabric was achieved through combinations of floor, wall, ceiling, and roof insulation, wall and floor materials (including brick & concrete walls, suspended and slab-on-ground floors as appropriate for the region), various glazing options including glazing area, and window shading solutions. Costs, prepared by Quantity Surveyors "Northcroft Australia Pty Ltd" for each of the study locations, are provided in Section 3.1 "Energy Efficiency Variations". A brief review of international codes was undertaken to ensure the energy efficiency variations covered a reasonable range (see Section 10).

- **Financial Variables**: The Net Present Value (NPV) analysis involves a number of variables including costs of measures undertaken to improve energy efficiency, discount rate, building life, energy price, the quantity and type of energy saved, and the perspective from which savings are considered – the dwelling occupant or society. The selected variables, listed in Section 3, have been incorporated in the analysis tool described in Section 5.

1.1.2 Modelling Phase

This phase undertook the energy and financial model development.

- **Energy Modelling**: The base house designs were modelled in NatHERS using the automated 'NATBAT' system developed by the Sustainable Energy Authority of Victoria. Table 2 quantifies the number of energy model variations. A total of 62,208 model runs had been originally proposed, but the assistance of SEAV permitted the scope of the work, and hence the number of model runs to be significantly increased.

  The results of the energy analysis for the various combinations of house type, location, comfort levels, type of energy, energy efficiency variations have been entered into a MS Access dataset. This dataset will was then used as the input to the cost-benefit modelling. Figure 20 (page 47) provides a diagrammatic overview of the analysis, while Table 2 provides a numerical summary.

Analysis Variable	Thermal Model Runs	
	Timber Floor	Concrete Floor
Climate Zones / Locations	12	
Base Dwelling Designs	6	
Orientation	4	
Lifestyle Variations – Time of day	2	
Lifestyle Variations – Heating Temperature	1	
Wall constructions	4	
Design / Construction / Occupant Variations	2,304	
Energy Efficiency Variations (including base case)		
•Thermal Insulation – roof	6	6
•Thermal insulation – wall	4	4
•Thermal insulation - suspended floor	3	
•Thermal insulation - slab-on-grade floor		2
•Glazing thermal performance	4	4
•Window shading	4	4
Energy Efficiency Variations	1,152	768
	2,654,208	1,769,472
TOTAL MODEL RUNS	**4,423,680**	

Table 2: Energy Model & Financial Analysis Variations

Notes to Table 2:

- Walls and roof colour medium.
- NatHERS does not evaluate edge insulation, only under slab insulation.
- Heating temperature is NatHERS thermostat setting for the climate zone.
- Unless explicitly stated, all defaults are NatHERS settings for that climate zone
- Framing materials are consistent with glazing type e.g. thermal broken frame with double glazing.

In addition to the analysis variables in Table 2, a number of additional model runs have been undertaken to investigate sensitivity to selected issues. These results are discussed in Section 4.6. Default values are provided in Appendix Section 12.3 in the form of the energy and building data output reports for each of the 6 houses used in the Cost Benefit Study, in their basic uninsulated configurations.

- **Financial Tool Development:** The spreadsheet model has been developed in Excel 2000, based on macros with an appropriate fronting menu. The model allows for changing of the critical parameters including:
    - Dwelling type
    - Location
    - Energy efficiency change (e.g. wall, roof & floor insulation, windows, shading)
    - Energy use and fuel type
    - Energy cost and escalation rate
    - Discount rate
    - Period of analysis.

1.1.3 Analysis and Outputs Phases

This report, and associated tool, represent the results for the analysis and output phases of the work.

1.2 NatHERS

NatHERS is a house energy performance modelling software tool developed by CSIRO, Division of Building, Construction and Engineering for the Australian and New Zealand Minerals and Energy Council. NatHERS provides an estimate of the energy needed to keep a dwelling thermally comfortable in a given location, and also provides a simple rating between 0 and 5 stars. The house is assumed to be operated under a standard occupancy schedule appropriate for the given location. Therefore the rating is not designed to predict the energy used by a particular family, but instead provides an accurate comparison of building performance on the basis of standardised criteria and hourly weather data[i].

NatHERS is built around a sophisticated simulation programme called CHENATH. The NatHERS programme provides a user friendly way for data on the house to be entered for use within the CHENATH programme. In addition NatHERS sets defaults for a range of issues that would otherwise require the user to have specialist simulation modelling understanding. The results from the CHENATH simulation are then fed back into NatHERS for conversion to Star Ratings.

NATHERS allows up to four occupied zones to be modelled:

- Living Area (required) (includes kitchen, lounge, dining rooms etc.)
- Bedrooms (required) (include bathrooms and hallway if centrally heated),
- Other Conditioned (optional): The Other Conditioned zone is used when heated and cooled zones of the same type exist in separate parts of the house.
- Unconditioned (optional): The Unconditioned zone is used for parts of the house that are not expected to be heated or cooled. e.g. laundries, toilets, storerooms, attached garages. etc.

Data about the house, its orientation and construction are coded and entered into the NatHERS programme, based on plan or actual measurements:

- Floor Plan dividing the house into appropriate zones.
- Length and height of each zone wall, measured from inside (m).
- Window dimensions (height and width (m)).
- Eaves Width and Offset from the top of the window and the eaves (m).
- Area of each zone (m^2).
- Materials of construction, including insulation levels, floor and window coverings.

---

[i] For further information see: http://www.mel.dbce.csiro.au/res-cap/tfe/research/nathers.htm

For the purpose of this study, NatHERS was run in the ‘Rating’ mode. The NatHERS Energy Report provides a one-page summary giving the star rating and key data (including a brief summary of construction details) for the building. An example for each house is given in Section 12.3.

The four NatHERS outputs of concern to this study are:

Heating Energy Required - the heating energy required to maintain comfort conditions inside the heated zones, for specific periods. It is different from the energy consumption because heating system efficiency is not included in the calculation. It is expressed in MJ/m^2.year (MegaJoules per square metre per year), as well as kWh/m^2.year (kiloWatt-hours per square metre per year).

Sensible Cooling Energy Required - the cooling energy required to maintain comfort conditions inside the cooled zones, for specific periods, not including the energy required for moisture removal (see Latent Cooling Energy below). The cooling system efficiency is not included in the calculation.

Latent Cooling Energy Required - the energy required for moisture removal during the cooling process, assuming refrigerated air conditioning. The cooling system efficiency is not included in the calculation.

Rating - The House Energy Rating is expressed in stars, stepped in half (0.5) Stars. The range is from 0 Star to 5 Stars, with 5 Stars being the most energy efficient. The Star rating is based on the sum of the heating energy and the cooling energy, and is adjusted according to local climate conditions. A Star rating scales is set for each of the climate zones.

Aside from the ‘Rating’, the other simulation programmes used in this study also provide data on the heating, sensible and latent cooling energy requirements for the modelled houses.

1.3 Administration

Study Committee meetings were held on 16 March 2001, 11 May 2001 and 10 August 2001

Formal reports were provided on 8 May 2001, 18 June 2001, 6 August 2001 with additional regular reporting being provided to the Project Manager and Chairman of the Study Committee. Trial versions of the financial tool were provided to the Study Committee on 2 July and 10 August 2001.

In addition to the base study, a contract addendum supported the preparation of Regulatory Impact Statement RIS 2001-1 “Energy Efficiency Measures For Services & Interim Roof Insulation For Houses” released by the Australian Building Codes Board on 6 August 2001. Reports were provided on 9 July 2001 for NatHERS based analysis of reflective foil laminate under roof coverings and on 3 August 2001 for EnCom2 based analysis.

2. HOUSE DESIGNS

This section provides a background to the house design selection process, including data on the types of houses currently being constructed in Australia. Plans for the six selected houses are included in Section 11.2. A small illustration of each house is provided in Figure 9, and area details in Table 6.

2.1 Introduction

This study sets out to examine the cost effectiveness of potential design and construction practice changes that are amenable to incorporation in the Building Code of Australia (BCA) for Class 1 buildings. Table 3 provides the BCA classification definitions for Class 1 buildings.

Class 1 – one or more buildings which in association constitute-

(a) **Class 1a** – a single dwelling being-
  (i) a detached house; or
  (ii) one or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit; or

(b) **Class 1b** – a boarding house, guest house, hostel or the like with a total floor area not exceeding 300 m² and in which not more than 12 persons would ordinarily be resident

which is not located above or below another dwelling or another Class of building other than a private garage

Table 3: BCA 1996 Class 1 Classification Definitions

Class 1b buildings can be expected to have similar exterior form to Class 1a(i) buildings. However Class 1a(ii) buildings will have one (if at the end of the row) or two (if in the middle of a row) walls in common with the other attached dwellings. In energy terms these common walls can be considered as 'isothermal' i.e. the temperatures on both sides are the same as both sides are conditioned. This results in no flow of heat, and hence no conditioning energy requirements. To ensure houses of this type are covered by the analysis, House 4 (see Figure 9) is a row house with neighbours on each side.

2.2 Archetypal Dwellings for Parametric study

The consultant team was asked to select the six plans with the concurrence of major stakeholders in this work. Accordingly, the following technique was used to identify suitably archetypical dwellings for this purpose:

1. From the recent study of the impact of thermal insulation regulations in Victoria (Energy Efficient Strategies, 2000), evaluate the 240 FirstRate data files representing the sample of Victorian housing practice in 1998-9 (i.e. in plans approved in that 12 month period).

2. From the recent study of the effectiveness of Mandatory Energy Performance Disclosure in the ACT (George Wilkenfeld and Associates, 2001), evaluate the ACTHERS files for 688 detached and 209 attached dwellings, representing the sample of ACT housing practice in the period from June 1998 to December 1999 (i.e. in plans approved in that 18 month period.

3. From data published by the ABS, establish a profile of recent new housing throughout the rest of the country.

4. Compare the candidate archetypes with the statistical data for new housing to confirm their validity and select the most appropriate six from among them.

Figure 2 (ACT sample) and Figure 3 (Victorian sample) graph the house floor area against the number of houses (ranked by floor area) in each sample. The batched data from the Victorian and ACT housing studies were grouped and separated into detached or attached dwellings[ii] and then sorted by floor area and the 25th percentile, median, 75th percentile, standard deviation, mean, maximum and minimum were identified for each type of dwelling. Further groupings were isolated from the Victorian data to identify single and 2 storey dwellings, as well as differences between 3 climate zones in the Victorian data.

It was noted that there was a variation in average dwelling size[iii] from 178m^2 in Shepparton, to 172m^2 in Ballarat and 206m^2 in Melbourne. It is likely that this reflects the relative affluence of these locations, rather than climatic factors. There was also a very slight increase (2.2 percentage points) in average Glazing Ratio, which is also unlikely to be attributable to climate.

For each set of data, an actual dwelling was also selected at or near the median area, to identify an actual house of approximately average proportions.

The key indicators for each house type are tabulated in Table 5, and for the average from each set in Table 4. The summaries of each full data set are also included in Section 11.1. Note that the left-most column of the summaries also indicates the size of the sample analysed and the number of different floor areas in those samples, in order to identify where numerous houses of the exact same area (presumably a set of cluster or town houses) were included in that sample.

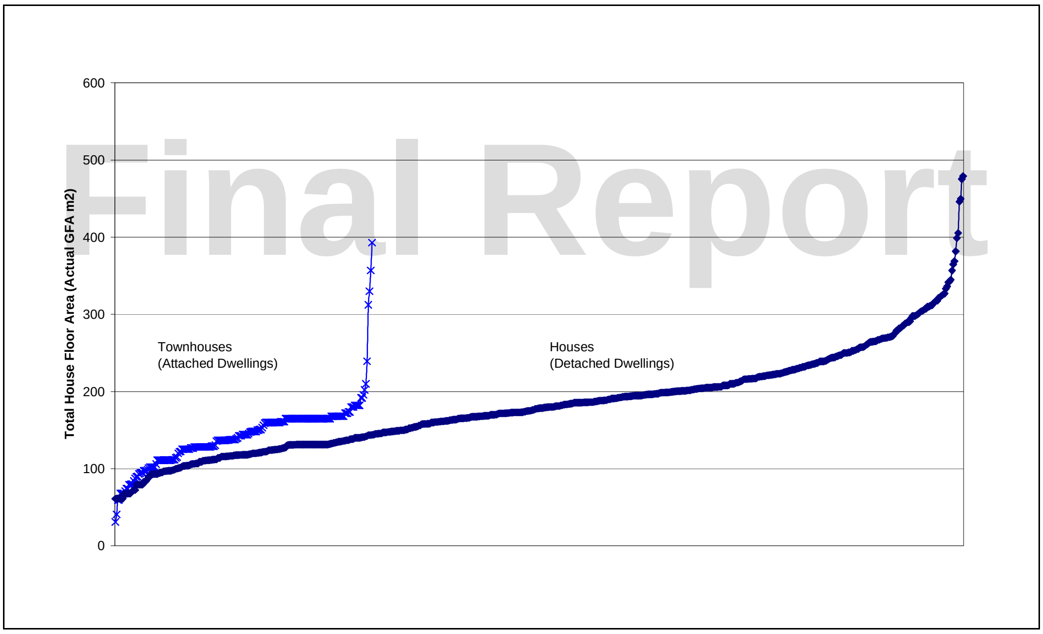


Figure 2: Dwelling Areas for ACT Statistical Data Set (Jun 98 to Dec 99)

Charts of the floor areas are also included: the ACT data sets in Figure 2 and Victorian data sets in Figure 3 show the distribution of dwelling sizes (with very large floor area outliers removed) and the consistency and similarity between each set. Comparable data for Australia as a whole, collated into frequency bands, is included in Figure 4 (ABS, 2001).

[ii] The Victorian sample comprised only Class 1 dwellings but the ACT sample included Classes 1 and 2. Accordingly, the ACT sample was pre-culled to eliminate all dwellings having an attached (shared) floor or ceiling to create a data set of Class 1 dwellings only.

[iii] Gross Floor Area (actual) estimated from the GFA (conditioned) available in the data set.

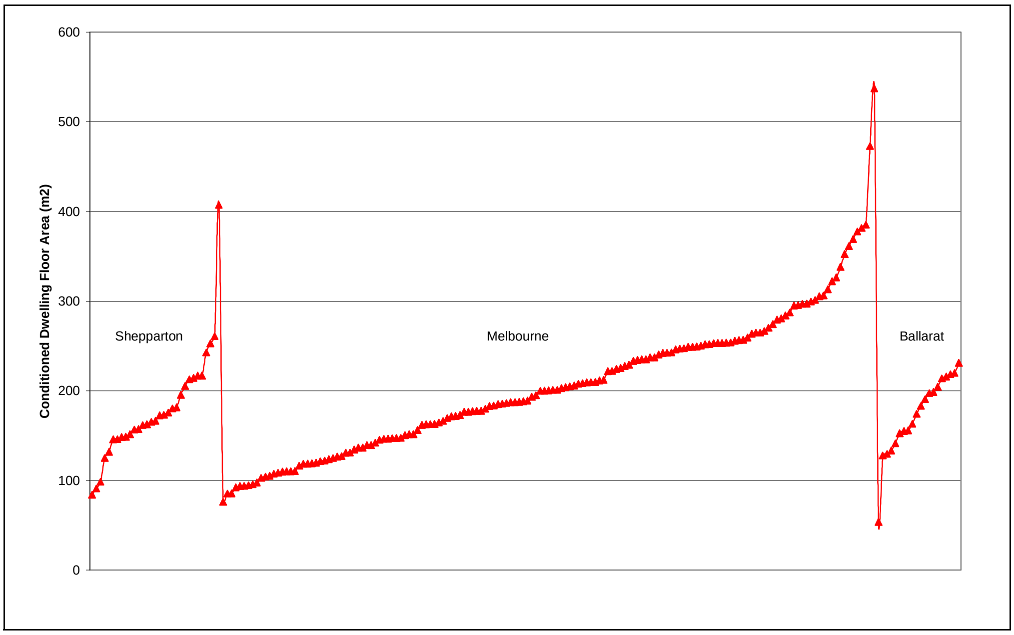


Figure 3: Floor Areas For Victorian Statistical Data Set - All Dwellings

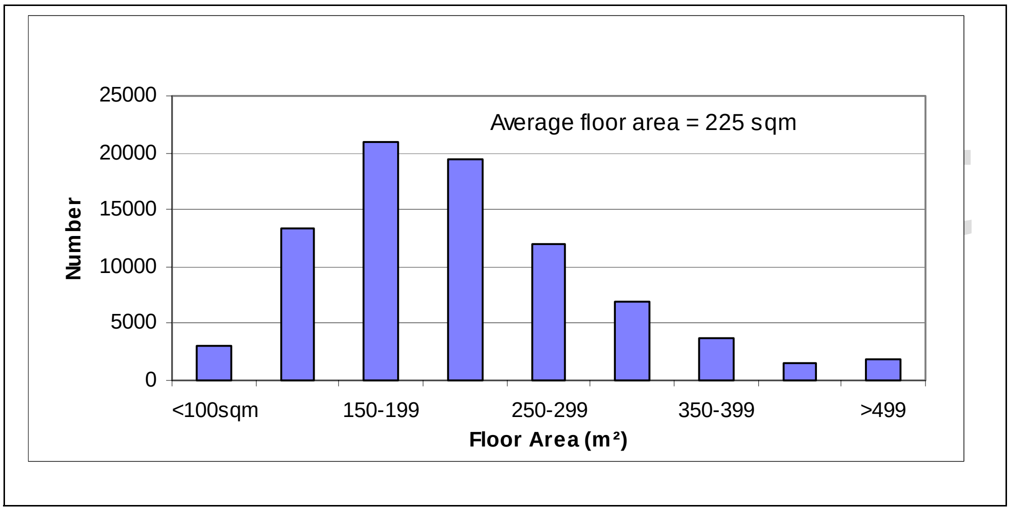


Figure 4: New house floor area ranges 1998/99 – All Australia

2.3 Dwelling Size

Dwelling size is commonly described by reference to the ‘floor area’ but this term is variously defined so that direct comparisons must be undertaken with care. Floor area definitions of relevance to this study include:

- **Net Floor Area (NFA)**:The area enclosed by the inside face of the external walls. This is used by Cordell and others as it gives a measure of the utility of the house which is independent of the external wall construction and its associated thickness. It is also the floor area used in the NatHERS software package. Despite the usefulness of this convention, it is little used in the housing industry.

- **Gross Floor Area (GFA):** The area enclosed by the outside face of the external walls. This is widely used by the housing and real estate industry (presumably because it is the largest expression of the size of a given product). It does however have a few variants, including:
- **Gross Floor Area (actual):** This value of GFA is the one in common usage in the housing and real estate industry, as described above. It is also used as the denominator for the energy intensity index ($MJ/m^2.a$) expression in the ACTHERS software package (the predecessor of FirstRate and used in the ACT until July 2001) and as such is the value available for the statistical review of ACT housing practice undertaken below. It is the GFA used in Table 4.
- **Gross Floor Area (conditioned):**This value of GFA is peculiar to the thermal performance analysis industry, being equivalent to the GFA (actual) above, EXCLUDING the unconditioned spaces such as services rooms. It is used as the denominator for the energy intensity index ($MJ/m^2.a$) to ensure that the annual energy demand of the dwelling is divided by only those parts of the house which are heated and/or cooled. It is the value input to the FirstRate software package and as such is the value available for the statistical review of Victorian housing practice undertaken below. It is indicatively 9.8% smaller than GFA (actual) for a given house.
- **Gross Floor Area (administrative):** This value of GFA is the one in common usage in the regulation of the housing industry. It comprises the GFA (actual) plus an allowance for attached garages, carports, porches and verandahs(e.g. in the ACT it is 50% of the roofed "external" floor area). The usefulness of this inflated GFA lies in its correlation with construction costs for a given building project and hence it is used for determining the cost-related fees associated with building approval. As the ABS merely collates data given it by the building approval authorities around the country, this value is the basis for the national statistics for housing size. Hence a change in trend from single to double attached garages would appear in the ABS statistics as an increase in the average floor area of new housing. Consequently care is required in applying the ABS statistics to this project.

By comparison with the Victorian and ACT measured sample, we have estimated the GFA (actual) as a ratio of the ABS values as 83% and have applied that value in selecting the size of the archetypes for simulation. Table 4 provides information for a sample of houses from ACT, Victoria and the Australian Bureau of Statistics for all Australia.

Name and Descriptor	Source	Floor Area (GFA m^2)	Glazing Ratio (%) (Glass/GFA)	Glazing Directionality (%)
ACT - Average Detached	ACT PALM	182.6	21.6%	41.9%
ACT - Average Attached	ACT PALM	142.8	18.6%	46.1%
ACT - Average 1 Storey Attached	ACT PALM	131.6	20.0%	46.9%
ACT - Average 2 Storey Attached	ACT PALM	146.9	18.1%	45.8%
Victoria - Average Detached	AGO / SEAV	217.8	19.7%	43.7%
Victoria - Ballarat Average Detached	AGO / SEAV	188.7	18.7%	43.7%
Victoria - Melbourne Average Detached	AGO / SEAV	225.6	20.2%	42.6%
Victoria - Shepparton Average Detached	AGO / SEAV	195.5	18.0%	48.9%
Victoria - Average Attached	AGO / SEAV	151.9	22.9%	46.3%
Victoria - Average 1 Storey Attached	AGO / SEAV	129.4	25.9%	45.2%
Victoria - Average 2 Storey Attached	AGO / SEAV	166.1	21.1%	47.0%
Australia - Average Detached June 2000*	ABS	230.1	N.A.	N.A.

Table 4: Key Housing Statistics

Note to Table 4: *including some fraction of attached Class 10 (e.g. garage)

2.4 Dwellings for Simulation

The following six house designs were selected for use in the simulation modelling:

7. **Detached House – Industry Example, Thermally Understood – Small Single Storey:** This house (BASE1000a) was selected due to its use as the base case house for the multiple simulations previously undertaken by SEAV in developing its house energy rating software FirstRate. In recognition of SEAV's contribution of assistance in the simulation phase of this project, and to allow that work to proceed in line with the tight project timetable, this dwelling design was pre-committed to be included in the 6 archetypes. It also has strong similarities with the commonly cited dwelling included in the alternatives, the Generic NatHERS (Window Energy Rating Scheme - WERS[iv]) House.

8. **Detached House – Medium Single Storey:** This house was selected as being an actual house very close in floor area to the 50%-ile in the set of houses studied in the Victorian housing study. It is considered typical of the average project home built in recent years.

9. **Detached House –Large Two Storey, Attached Garage:** This house was selected as being an actual house very close in floor area to the 75^{th} percentile in the set of houses studied in the Victorian housing study. It is considered typical of the large 2 storey project home built in recent years.

10. **Townhouse – Two-storey, Two Neighbours, Attached Garage:** This townhouse was selected from the Victorian sample for recommendation as representative of a housing style with very low surface area exposed to the weather and hence a relatively low sensitivity to the benefits of wall insulation.

11. **Detached House - High Ventilation Design:** This house was put forward by Prof Steven Szokolay, University of Queensland, as an archetypical "Humid Tropical" house with long plan form and highly effective cross flow ventilation and elevated construction.

12. **Detached House - Passive Solar Design:** Passive solar design is well understood but there is no consensus as to definition. A minimum definition was recently adopted for work for the AGO (Energy Efficient Strategies, 2000) and is used here for reference purposes:

It is necessary to set some criteria by which the application of passive solar design may be judged. As a basic measure for this study, three criteria were selected:

- *The house must achieve a minimum 3.5 NatHERS Stars.*
- *The house must have a reasonably high thermal performance sensitivity to change in orientation (this is a key indicator for passive solar design), a performance range of 20% or more from most to least favourable orientation of the house was adopted for this criterion.*
- *Given a 20% range of possible performance levels (depending upon orientation) it is important that the house is in fact favourably oriented (essential qualification for passive solar design). An as sited performance that is within 5% of the house's optimal energy performance was adopted for this criterion.*

For this project a more stringent definition is appropriate, as we wish to establish whether each energy efficiency modification is economically justified in the context of high performance design. In such cases, savings from added insulation (for example) will be diminished by the large component of "free" solar heating in such houses in temperate and cool temperate

[iv] for further information on the Australasian Window Council's WERS, see www.wers.net

climates. Accordingly we have adapted a strongly directional project home by the Canberra firm Millenium Homes (designed by Strine Design) for investigation.

A number of other designs were considered, and these are briefly described in Table 5 which provides a summary of source and area measurements for these houses.

No	Name and Brief Description	Source	Floor Area[v] (GFA m²)	Glazing Ratio (%) (Glass/GFA)	Glazing Directionality[vi] (%)
1	BASE1000a Small Single Storey	SEAV	173.0	19.2	38.3 / 17.2
2	Victoria – Melbourne Medium Single Storey	AGO/SEAV	202.7	21.2	26.3 / 11.4
3	Victoria - Melbourne Large Two Storey	AGO/SEAV	253.7	21.3	45.6 / 10.4
4	Victoria – Melbourne Townhouse, 2-storey, 2 neighbours	AGO/SEAV	109.6	19.3	84.8 / 0
5	Cross ventilated humid tropics	Szokolay	156.0	34.9	42.6 / 9.4
6	Passive Solar Design	Strine Design	171.9	32.2	57.9 / 0
	Alternative Plans (not used)				
7	Cordell Type C Medium Single Storey	Cordell	125.0	23	41 / 17
8	Cordell Two Storey Large Attached Garage	Cordell	255.0	14	69 / 31
9	Pentactics Industry example, attached garage	Wolfe / HIA	132.4	25	37 / 13
10	Cordell Type A Small Single Storey	Cordell	86.0	24	48 / 5
11	Zero lot line Small Single Storey	AGO/SEAV	124.3	18	46 / 0
12	End single storey townhouse Semi-detached	AGO/SEAV	124.3	18	46 / 0
13	Generic NatHERS (WERS) Medium BV bungalow	Lyons/NatHERS	157.5	22	34 / 17
14	Passive Solar – Based on Generic NatHERS (WERS) Design [vii]	Energy Partners	157.5	22	49 / 10
15	Victoria – Melbourne Townhouse, 2-storey, 2 neighbours	AGO/SEAV	132.2	18	81 / 0
16	Vabtex Cross ventilated humid tropics	Szokolay	129.0	32	53 / 15
17	Vitek Residence Passive Solar Design	Strine Design	117.0	27	67 / 0

Table 5: Key Indicators for Proposed Dwelling Plans (and Alternatives)

Table 6 provides summary area details of the selected houses. Section 11 provides a drawing of each of the selected houses. The glazing directionality (the relationship between the maximum and minimum glazing areas) is most extreme in the cases of the row house (as it has no side windows, only neighbouring row houses) and the 'Passive Solar Design' (which has no end windows).

[v] Gross Floor Area (actual) adjusted from the raw data where necessitated by the nature of the source.
[vi] Glazing area in the most / least glazed external wall divided by total glazing area, expressed as a %.
[vii] Passive Solar House created by changing window directions of WERS house.

Name	Conditioned Floor Area (CFA m²)	Net Floor Area (NFA m²)	Garage & Portico NFA (m²)	Gross Floor Area (GFA m²)	Total External Wall Area (m²)	Glazing					
						Total Area (m²)	Ratio (%)	Max (m²)	Min (m²)	Max (%)	Min (%)
1. Small Single Storey	142.8	157.0	0.0	173.0	94.7	33.2	21.1	12.7	5.7	38.3	17.2
2. Medium Single storey	168.2	185.9	47.8	202.7	86.2	43.0	23.1	11.3	4.9	26.3	11.4
3. Large Two Storey	202.8	227.9	33.8	253.7	189.3	54.0	23.7	24.6	5.6	45.6	10.4
4. Townhouse	83.9	93.8	20.9	109.6	28.2	21.1	22.5	17.9	0.0	84.8	0.0
5. Cross Ventilated Tropics	138.2	149.5	0.0	156.0	117.6	54.5	36.5	23.2	5.1	42.6	9.4
6. Passive Solar Design	151.8	161.2	0.0	171.9	88.2	55.4	34.4	32.1	0.0	57.9	0.0

Table 6: Selected Houses – Areas

Notes to Table 6:

- Floor areas used for thermal modelling exclude garage
- Floor areas used for costing INCLUDE garages and porticos, porches, etc.
- External wall area for modelling excludes party walls to neighbours and garages, and includes non-glazed doors because NatHERS ignores them.
- Costing for House 5 includes subfloor wall area for elevated Queensland construction.
- Modelling assumes doors in House 4 living area - to rear garden & House 5 doors onto Verandah are all glazed.

3. PRICING DATA

The information on costs for energy efficiency alternatives was specifically prepared for the project by Northcroft (Australia) Pty Ltd. for the house construction and variations, and by Energy Partners for fuel prices.

Please note that all prices in this report are **GST exclusive**. This allows for any future alteration to the GST rate. To convert prices to final consumer prices, add 10% GST.

3.1 Energy Efficiency Variations

Variation of the thermal performance of the building fabric can be achieved through combinations of floor, wall, ceiling, and roof insulation, the wall and floor materials (including brick & concrete walls, suspended and slab-on-ground floors as appropriate for the region), various glazing options including glazing area, and window shading solutions. A brief review of two international building energy efficiency codes was undertaken to ensure the energy efficiency variations covered a reasonable range (see Section 10). New Zealand was used as a check for temperate climates, and the State of Hawaii, USA, for tropical climates.

Northcroft (Australia) Pty Ltd is a member of the Northcroft Group established in England in 1840, with over twenty years experience in Australia. Northcroft has over eighteen years experience in preparing costing information for specific buildings to be built in a range of locations throughout Australia. In providing construction cost advice for this study, Northcroft has researched costing data from Northcroft archives and current Building Cost Guide Publications, in particular Cordell Building Information Services.

3.1.1 Approach

Northcroft developed a Model Concept Cost Plan, with outline of probable costs, for each of the six typical designs provided for research. Each Model was costed as an "Individual House" with medium standard finishes and selections, assuming a competitive tender market. The costs do not attempt to mirror costs applicable in the mass market "Project Home" industry sector.

The cost advice provided, analysed construction methods and specification variables in six building elements:

- External walls;
- Internal walls;
- Roof;
- Ground floor;
- Windows; and
- Shading.

This elemental cost analysis was used to derive incremental cost differences for alternative construction methods and insulation techniques. This elemental cost data was then applied to the twelve regional locations. Regional applications have been assessed based on available data and rationalising the regional cost to the State Capital industry base. (see Section 3.3, Table 13). Each model assumes a level building platform and standard engineering of site conditions.

Then in each case the following methodology was used:

- Base building costs per square metre for each model have been derived through the use of costed elemental ratios to total building cost.
- Dimensions are as read or scaled off the drawings.
- Elemental costings are based on the elemental configurations given in Section 13.3.
- The regional sensitivity building cost index and cost differences are based on research of published regional indices.

- Elemental costings do not include for final surface finishes, such as paint finish, wall trimmings, carpet covering and/or tiling.

3.1.2 Construction Details

Section 13.3 provides descriptions of construction details for each roof, wall, floor, glazing and shading type, including the expected R-value for the overall construction. The text below provides additional background to the pricing methodology.

- **Windows**
  - Base window configuration is assumed as aluminium domestic sliding windows (50% opening) with powder coated anodised frames and 6 mm clear float glazing.
- **External Wall**
  - Brickwork is assumed to be standard metric clay bricks laid in 1:1:6 cement mortar
  - Chamfered siding 150 mm x 19 mm thick Oregon shiplap boarding is assumed for Perth due to availability. All other capital cities are priced with 150 mm x 25 mm thick boarding.
  - Reflective aluminium foil is assumed to be medium weight (368 gm/m²) fire resistant foil (e.g. Sisalation)
  - Expanded polystyrene insulation board is priced where applicable.
  - Both brickwork and blockwork is assumed to have bagged finish internally ready for painting. Blockwork is also bagged externally.
  - No skirting or other trimming is assumed.
  - Cement rendering is assumed to be 10 mm thick where required.
  - External walls to garage are not insulated.
- **Roofing**
  - For roof framing, F8 hardwood is assumed for Victoria, F14 hardwood is assumed for Queensland and the rest are priced with F11 hardwood.
  - Roof plumbing (e.g. gutters and down pipes) is not included in the pricing for roofing, but it is included in the overall costs for the houses
  - Concrete roof tiles are standard square pattern. Pricing allowances are made for roofing accessories and steeper roof pitch and exclude roof plumbing.
  - 6 mm thick F.C. eaves lining is assumed in the pricing for both the eaves and the verandah option.
  - 150 mm x 150 mm F11 hardwood posts @ 3000 centres with concrete pad footings are assumed for support of verandah (F8 hardwood in Victoria and F14 hardwood in Queensland).
  - Fibreglass insulation segments (e.g. "Batts") are assumed.
- **Flooring**
  - For floor framing, F8 hardwood is assumed for Victoria, F14 hardwood is assumed for Queensland and the rest are priced with F11 hardwood.
  - 22 mm thick particle board floor is assumed
  - 400 mm x 400 mm perimeter beam is assumed for timber floor frame option.
  - 100 mm thick raft slab with 300 mm x 400 mm edge beam is assumed for slab on ground option.
  - No allowance is made for site condition in the costing.
  - Ground condition allowed in the costing is for a flat greenfield site with medium soil.

Description (Wall/Case)	A / 1	B / 2	C / 3	D / 4	E / 5
Wall constructions	Weatherboard	110mm Brick Veneer	Cavity Brick	Concrete Block	
Wall Insulation Type 1	Reflective Foil	Reflective foil	30mmPolystyrene	28mm Polystyrene	
Wall Insulation Type 2	R1.5 fibreglass	R2 fibreglass	40mm Polystyrene	38mm Polystyrene	
Wall Insulation Type 3	R2 fibreglass	R2 fibreglass + foil	50mm Polystyrene	47mm Polystyrene	
Roof	Foil under tiles.	R1 Ceiling	R3 Ceiling	R5 Ceiling	Foil + R3 Ceiling
Suspended floor	Dropped foil	R2 fibreglass			
Slab-on-grade floor	25mm Polystyrene to 450mm depth				
Glazing	Single clear 6mm (SG Clr) Aluminium frame	Single tinted 6mm (SG Tint) Aluminium frame	Double Clear (DG Clr 4/8/4) Thermal broken frame	Double Low-E (DG,LE,HI) Thermal broken frame	
Shading	No Eaves	600mm Eaves)	Fabric awnings	3.6m Verandah	

Table 7: Construction Brief Descriptions

Table 7 provides a brief description of the various wall, roof, floor and glazing types with the energy efficiency alternatives. Note that no insulation present in base cases for each component. Table 48 (Section 13.3) provides additional details of the constructions.

3.2 Energy Efficiency Options - Prices

Table 8 through Table 12 provide the pricing data for House 1 located in Sydney. Similar tables were prepared for the project for Melbourne, Brisbane, Perth and Adelaide. The total house cost per unit floor area is provided in Section 13.1, with the unit area cost of each energy efficiency alternative for each house in the Sydney location provided in the tables in Section 13.2.

Each of Table 8 through Table 12 shows for the given component for the base cost, the construction alternative (e.g. different wall types) and each of the energy efficiency options

For example, Table 9 lists four alternative wall constructions (timber frame weatherboard, timber frame brick veneer, cavity brick and block work) with a base price for each construction on both a per square meter and whole house ‘extended element cost’ basis. The marginal additional cost (“extra over cost”) for each of the energy efficiency alternatives is then provided in the same two forms. Thus for the brick veneer wall (wall Type 2), the base cost of $137.00 per square metres gives an overall house cost of $15,070.39. The additional cost for Type 1 insulation (in this case reflective foil laminate) is $1.60 per square metre, giving a total cost of $15,246.39 for the house with this level of insulation. This pricing information was then included in the financial tool.

		Type A (pitched roof)	Type B (flat roof)
	Roof: Area 173 m²	19 thick concrete tile roof, timber roof frame (100*50 rafters @ 450 ctr) and 10 thick plasterboard ceiling lining (30 degree pitch)	19 thick concrete tile roof, timber roof frame (100*50 rafters @ 450 ctr) and 10 thick plasterboard ceiling lining (Flat roof)
BASE CASE	Cost	$100.10 /m²	$71.85 /m²
	Extended Element Cost	$17,316.56	$12,430.61
TYPE 1 INSULATION	Extra Over Cost	$5.45 /m²	$4.10 /m²
	Extended Element Cost	$18,259.03	$13,139.91
TYPE 2 INSULATION	Extra Over Cost	$5.40 /m²	$5.40 /m²
	Extended Element Cost	$18,251.48	$13,365.53
TYPE 3 INSULATION	Extra Over Cost	$8.00 /m²	$8.00 /m²
	Extended Element Cost	$18,700.43	$13,814.48
TYPE 4 INSULATION	Extra Over Cost	$12.60 /m²	$12.60 /m²
	Extended Element Cost	$19,496.02	$14,610.07
TYPE 5 INSULATION	Extra Over Cost	$13.45 /m²	$12.10 /m²
	Extended Element Cost	$19,642.90	$14,523.78

Table 8: Pricing – Roof (House 1 - Sydney)

		Type A (1)	Type B (2):	Type C (3):	Type D (4):
	External Walls: Area 110 m²	Timber wall frame (90*35 studs @ 450 ctr) with 150*25 Oregon ships-lap boarding and building paper underneath external cladding, 10 thick plasterboard internal lining	110 thick clay brick veneer, timber wall frame (90*35 studs @ 450 ctr) with paper outside frame and 10 thick plasterboard internal lining	Cavity brick wall with one 110 thick clay face brick skin and one 110 thick clay common brick skin	200 thick hollow block work walls
BASE CASE	Cost	$108.80 /m²	$137.00 /m²	$170.80 /m²	$82.00 /m²
	Extended Element Cost	*$11,968.00*	*$15,070.39*	*$18,787.62*	*$9,020.33*
TYPE 1 INSULATION	Extra Over Cost	$1.60 /m²	$1.60 /m²	$10.31 /m²	$25.25 /m²
	Extended Element Cost	*$12,144.00*	*$15,246.39*	*$19,921.72*	*$11,797.83*
TYPE 2 INSULATION	Extra Over Cost	$6.95 /m²	$8.15 /m²	$14.20 /m²	$29.10 /m²
	Extended Element Cost	*$12,732.50*	*$15,966.89*	*$20,349.62*	*$12,221.33*
TYPE 3 INSULATION	Extra Over Cost	$8.15 /m²	$9.70 /m²	$15.20 /m²	$30.10 /m²
	Extended Element Cost	*$12,864.50*	*$16,137.39*	*$20,459.62*	*$12,331.33*

Table 9: Pricing - External Walls (House 1 - Sydney)

		Type A: (Concrete Slab)	Type B (suspended timber)
	Ground Floor: Area 173 m²	100 thick reinforced concrete slab with 400*300 mm perimeter footings	Timber floor frame (200*75 bearers @ 1800 ctr with 100*50 joists @ 450 ctr) with 22 thick particleboard floor lining, 400*400 mm perimeter footings, 110 thick brickwork subfloor walls, 110 thick attached piers, 230*230 piers and 600*600*250 reinforced concrete pad footings
BASE CASE	Cost	$71.00 /m²	$100.10 /m²
	Extended Element Cost	*$12,283.00*	*$17,317.81*
TYPE 1 INSULATION	Extra Over Cost	$10.00 /m²	$4.05 /m²
	Extended Element Cost	*$14,013.00*	*$18,018.46*
TYPE 2 INSULATION	Extra Over Cost		$10.80 /m²
	Extended Element Cost		*$19,186.21*

Table 10: Pricing - Ground Floor (House 1 - Sydney)

		Type A(1)
	Windows: *Area 33 m²*	Aluminium framed sliding windows
BASE CASE	*Cost*	$207.20 /m²
	Extended Element Cost	*$6,837.60*
TYPE 1 GLAZING	*Extra Over Cost*	$30.00 /m²
	Extended Element Cost	*$7,827.60*
TYPE 2 GLAZING	*Extra Over Cost*	$115.70 /m²
	Extended Element Cost	*$10,655.70*
TYPE 3 GLAZING	*Extra Over Cost*	$145.70 /m²
	Extended Element Cost	*$11,645.70*

Table 11: Pricing - Glazing (House 1 - Sydney)

	Type A (1):	*Type B (2):*	*Type C (3)*	*Type D (4)*
SHADING:	No eaves (0 m²)	600 mm eaves overhang on all sides with 6 mm FC eaves lining (35 m²)	Closed fabric awnings over all windows (Canvas fabric roller awning with aluminium frame, hand crank operated complete with fixed guides) (19 m²)	3600 wide timber framed verandah (Timber framed with 100*50 rafters @ 450 ctr) with concrete roof tiles, 6 mm thick FC soffit lining and 150*150 post with 450*450*450 mass concrete column @ 3000 ctr (252 m²))
Cost	$0.00 /m²	$101.70 /m²	$266.65 /m²	$102.95
Extended Element Cost	*$0.00*	*$3,559.49*	*$5,066.40*	*$25,943.04*

Table 12: Pricing - Shading (House 1 - Sydney)

3.3 Regional Variations

Table 13 provides the comparison of costs for the twelve selected locations, based on unity for the highlighted state or territory capital city. It can be seen that the variations in costs is from 0.94 (i.e. 6% less) in Hobart to 1.28 (i.e. 28% more) in Darwin.

	Location	**Cost Ratio**
	NEW SOUTH WALES & ACT	
1	Sydney	1.00
2	West Sydney	1.00
3	Canberra	1.02
	VICTORIA & TASMANIA	
4	Melbourne	1.00
5	Mildura	1.02
6	Hobart	0.94
	QUEENSLAND	
7	Brisbane	1.00
8	Townsville	0.99
9	Longreach	1.15
	WESTERN AUSTRALIA	
10	Perth	1.00
	SOUTH AUSTRALIA & NT	
11	Adelaide	1.00
12	Darwin	1.28

Table 13: Regional Pricing Variations

Table 14 lists for each wall type for House 1 the base cost and the incremental cost for the three energy efficiency alternatives. The differences between cities for each construction type can be seen – for example while weatherboard walls are common in many locations they are not in Perth, and thus have a higher base cost. Cavity brick is popular in Perth, and is thus lower in cost than in many other locations. Although the individual energy efficiency alternatives (Types 1 to 4) vary in incremental cost (shown by the ratio Min:Max row), the relationship in the total cost (i.e. the base cost plus the incremental cost) are very similar.

Location	Wall Type	Type 1	Type 2	Type 3	Type 4
Adelaide	Weatherboard	$109.30 /m²	$2.20 /m²	$6.65 /m²	$7.85 /m²
Brisbane	Weatherboard	$100.40 /m²	$0.95 /m²	$6.25 /m²	$7.30 /m²
Melbourne	Weatherboard	$104.30 /m²	$1.45 /m²	$6.40 /m²	$7.50 /m²
Perth	Weatherboard	$130.35 /m²	$2.00 /m²	$7.05 /m²	$8.20 /m²
Ratio Min:Max		77%	43%	89%	89%
Ratio Total Min:Total Max			77%	78%	78%
Adelaide	Brick veneer	$115.15 /m²	$2.20 /m²	$7.85 /m²	$10.05 /m²
Brisbane	Brick veneer	$110.75 /m²	$0.95 /m²	$7.30 /m²	$8.25 /m²
Melbourne	Brick veneer	$120.60 /m²	$1.45 /m²	$7.50 /m²	$8.95 /m²
Perth	Brick veneer	$118.70 /m²	$2.00 /m²	$8.20 /m²	$10.20 /m²
Ratio Min:Max		92%	43%	89%	81%
Ratio Total Min:Total Max			92%	92%	92%
Adelaide	Cavity brick	$139.75 /m²	$11.00 /m²	$15.70 /m²	$16.70 /m²
Brisbane	Cavity brick	$134.45 /m²	$9.60 /m²	$12.85 /m²	$13.85 /m²
Melbourne	Cavity brick	$156.85 /m²	$7.90 /m²	$9.95 /m²	$10.95 /m²
Perth	Cavity brick	$135.65 /m²	$10.95 /m²	$14.75 /m²	$15.75 /m²
Ratio Min:Max		86%	72%	63%	66%
Ratio Total Min:Total Max			87%	88%	88%
Adelaide	Hollow block	$81.45 /m²	$20.10 /m²	$24.80 /m²	$25.80 /m²
Brisbane	Hollow block	$70.25 /m²	$27.80 /m²	$31.10 /m²	$32.10 /m²
Melbourne	Hollow block	$86.95 /m²	$28.35 /m²	$30.40 /m²	$31.40 /m²
Perth	Hollow block	$90.20 /m²	$21.10 /m²	$24.90 /m²	$25.90 /m²
Ratio Min:Max		78%	71%	80%	80%
Ratio Total Min:Total Max			85%	86%	86%

Table 14: External Wall Pricing Comparison (House 1)

Table 15 provides a Capital Cities Cost Index with Sydney as base (i.e. Sydney = 100) in order to check the location pricing relationships developed for this study. The two alternatives are based on:

- the pricing for Houses 1 to 6 from this study
- regional pricing information provided to the study by Cordell Construction Information Services Pty Ltd

Table 15 shows that the Cost Indices derived from the House Models are similar to those from Cordell, with the exception for Melbourne and Brisbane. The most probable reason is a difference in the Northcroft cost data for blockwork, compared to the Cordell's more general market survey.

	Sydney	Melbourne	Brisbane	Perth	Adelaide
Based on Cost from House Models 1 – 6	100%	91%	85%	95%	87%
From Cordell Building Information	100%	95%	89%	96%	87%

Table 15: Capital Cities Cost Index Comparison (Base Sydney = 100)

3.4 Double Glazing

Figure 5 compares the NSW Building Price Index with the price for double glazed windows, as reported in Cordells' "Housing Building Cost Guide" for NSW. Over the ten years 1992 to 2001, the price of double glazed windows fell by 17%, whilst the NSW Building Price Index increased by 44%. It would be expected that with increase markets for double glazing, the price would continue to fall.

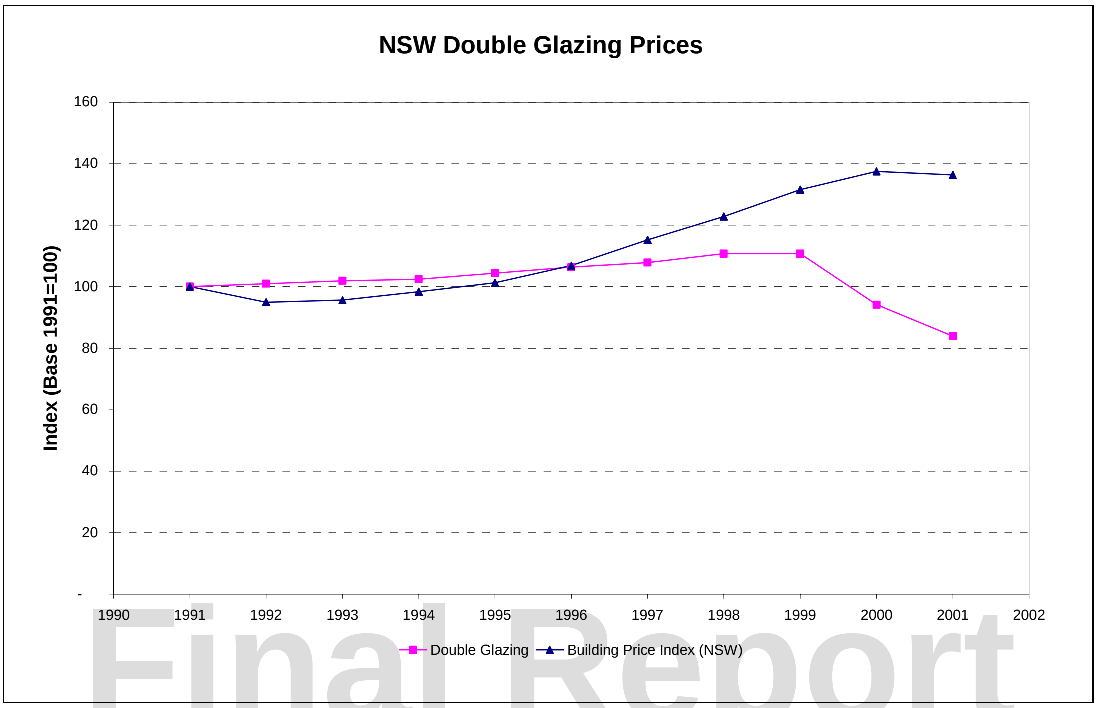


Figure 5: Cost of Double Glazing In NSW (1990 = 100)

The analysis of this long term series will be complicated in future years, as the comparison will need to take into account the removal of wholesale sales tax after the introduction of GST on 1 July 2000.

The Australian representative of one of the largest suppliers of flat glass to fabricators in North America commented:

> *"In Australia … the pricing for standard clear and clear Insulating Glass is already at or below the US equivalent price, and it is expected that the price of Low-E Insulating Glass in Australia will quickly fall to around US levels as soon as there is any reasonable volume in the Australian market. Already, the supply price of Low-E glass for local fabrication in Australia is competitive compared to similar selling prices in North America"*

3.5 Climate:

Table 16 lists the 12 Climate Zones, and their relationship to the proposed Climate Zones illustrated in Figure 6. As shown in Table 16, each of the proposed Climate Zones is covered by one of the study climate zones.

#	Location	Climate Zones - Descriptive	NatHERS Zone Number
1	Darwin, NT	Hot humid summer – warm winter	1
2	Longreach, QLD	Hot dry summer – warm winter	3
3	Townsville, QLD	Hot humid summer – warm winter	5
4	Brisbane, QLD	Warm humid summer – mild winter	10
5	Perth, WA	Warm temperate	13
6	Sydney, NSW	Warm temperate	17
7	West Sydney, NSW	Mild temperate	28
8	Mildura, VIC	Hot dry – cool winter	27
9	Adelaide, SA	Mild temperate	16
10	Melbourne, VIC	Mild temperate	21
11	Canberra, ACT	Cool temperate	24
12	Hobart, TAS	Cool temperate	26

Table 16: Study Climate Zones

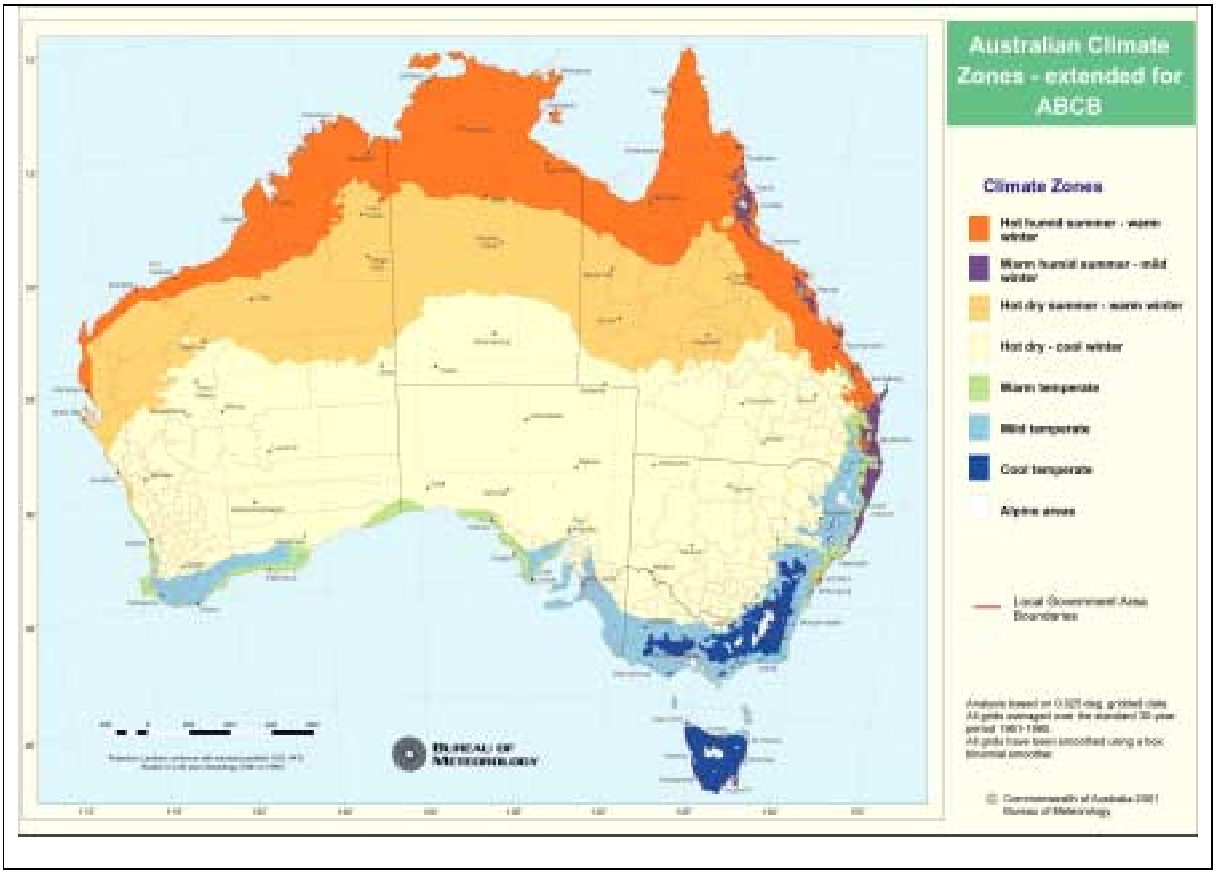


Figure 6: Possible Climate Zones

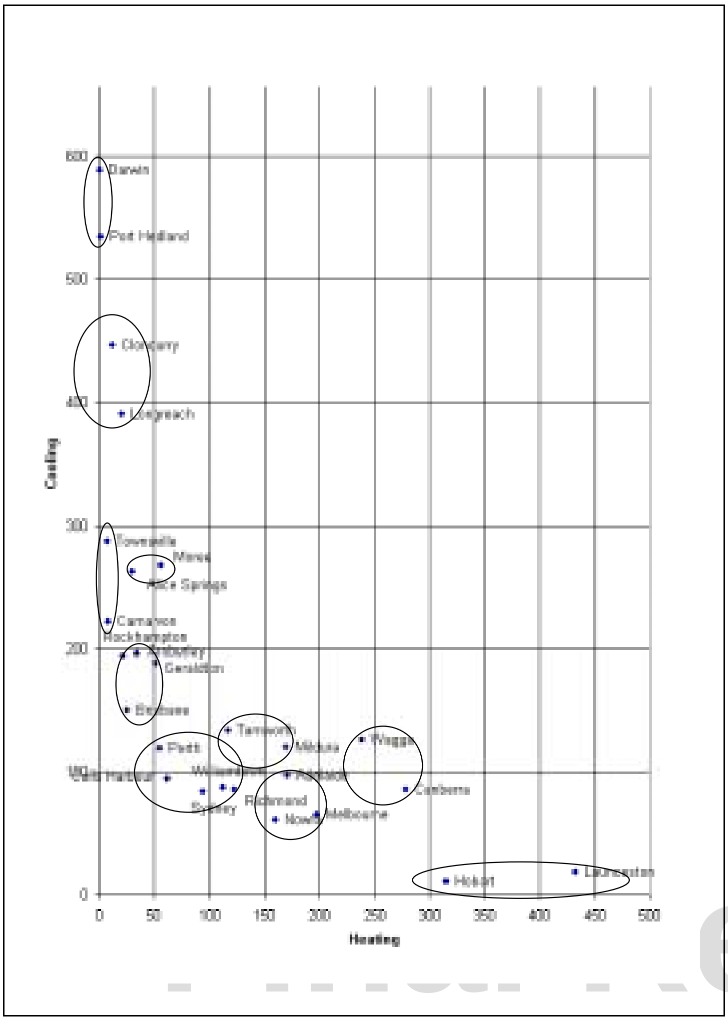


Figure 7: Heating vs. Cooling Energy Use

While the NatHERS developed twenty-eight climate zones for the purposes of assessing house energy ratings, such a large number of zones would add unacceptable complexity should they be used in the BCA. The NatHERS zones were originally defined by firstly comparing climatic averages with the simulated heating and cooling energy use of a group of houses in those (58) locations where hourly data for simulation was available. From this analysis a set of correlation equations was defined which related climatic average information, to the average heating and cooling energy use of a group of houses. Heating correlated well with heating degree days (18 °C), while cooling was related to cooling degree days (25 °C), latitude and maximum wet bulb temperature. This allowed the development of heating and cooling parameters for all locations which have climatic average information. Climates were then classified by grouping together locations with similar heating and cooling parameters.

By using a similar technique for allocating regulatory climate zones to that used for NatHERS synergies can be developed between the regulations and performance tools. By at least aligning the climate zone boundaries of the regulatory climate zones with the NatHERS zones we can avoid the potential problem of two locations being in the same NatHERS zone but different regulatory zones and vice versa.

Figure 7 compares the average heating energy use plotted against the average cooling energy use for each of the twenty-eight NatHERS climate zones (SEAV 2001). This average energy use was determined from NatHERS simulations of 250 variations of the one house in each location. These variations included changes to orientation, window areas, thermal mass, shading and insulation levels. The NatHERS climates were then combined by comparing which climates are located near to each other on this graph.

3.6 Energy Types & Prices:

Electricity (Table 17) and natural gas (Table 18) prices have been obtained for the base locations. 'Fixed" or 'daily charges' have not been included (as they have to be paid). As many of the domestic tariffs are stepped (i.e. have a higher cost per unit the less the amount of energy used, with the first step about 300 kWh/quarter, and sometimes another around 600 or 1000 kWh/quarter), the marginal cost is assumed to be the 'Balance' cost (i.e. after the tariff steps), with no allowance for separate meter or daily supply charges. In general this marginal cost is less than the cost per unit for the first one or two steps, so this approach is not to the disadvantage of energy efficiency. For comparison, Table 17 provides the 'average' cost for a household using 5,000 kWh per year. Summer and winter supplies cannot be separately priced.

NatHERS Zone Number	Location	Electricity Company	Tariff	c/kWh All / Balance	Average c/kWh 5,000 kWh/yr
24	Canberra	ACTEW Corporation	Domestic	8.40	10.68
24	**	Advance Energy	Domestic	11.77	13.36
24	**	Australian Inland Energy	Domestic	9.99	11.26
17	**	EnergyAustralia	Domestic	10.08	11.27
17	Sydney	Great Southern Energy	Domestic	10.00	11.40
17	**	Integral Energy	Domestic	10.44	11.37
28	West Sydney	NorthPower	Domestic	10.93	13.06
27, 21	Mildura, Melbourne	Victorian DB s	GD & GR	12.76	15.00
3, 5, 10	Longreach, Townsville, Brisbane	Queensland EC s	Tariff 11	9.43	11.72
16	Adelaide	AGL South Australia	Tariff 110	12.95	14.66
13	Perth	Western Power Corporation	Tariff A1	12.67	14.37
25	Hobart	Aurora Energy	Tariff 31/41	7.66	13.87
1	Darwin	Power and Water Authority	Domestic	12.75	14.58

Table 17 : Electricity Tariffs (excluding GST)

Notes to Table 17:
"All/Balance" is the marginal tariff for that location if there are one or more steps in the tariff
"5,000 kWh/yr" is the average tariff for that location if 5,000 kWh/yr are used
** These suppliers also service country NSW which is not specifically included in the study
Source: "Electric Prices in Australia 2000/2001" Electricity Supply Association of Australia Limited

NatHERS Zone Number	Location	Gas Company	c/kWh All / Balance
24	Canberra	Australian Gas Light (AGL)	4.33
17	Sydney	Australian Gas Light (AGL)	4.33
28	West Sydney	Australian Gas Light (AGL)	4.33
27	Mildura	Origin Energy	2.83
21	Melbourne	Origin Energy *	3.21
3	Longreach	N/A	N/A
5	Townsville	Origin Energy	7.05
10	Brisbane	Origin Energy *	4.16
16	Adelaide	Origin Energy	3.02
13	Perth	Alinta Gas	2.78
25	Hobart	N/A	N/A
1	Darwin	N/A	N/A

Table 18: Gas Tariffs (excluding GST)

Note to Table 18:
* - more than one gas supplier available in these locations, so lowest cost supplier used
Source: Telephone checking with individual gas supply companies, June 2001.

3.6.1 Energy Price Escalation

The default energy price escalation is set at 0% per year in the analysis tool. However this rate could be set at a higher value to take account of changes in energy supply plant, transmission and the potential impact of a GHG carbon charge.

For example, for electricity, examination of the average electricity retail prices (ESAA, 2001) in real terms shows that for the 'national grid' states there was a decrease in the real price of electricity during the early years of corporatisation and privatisation reflecting both rationalisation and competitive pressures. However, since 1997/8 there has been a modest, but steady, increase of indicatively 1% per year. A GHG cost internalisation over the coming decade can be projected as 1 c/kWh ($10/tonne CO_2) which approximates to an additional escalation of 1% per year. Thus an escalation rate of 2% per year could be justified for electricity.

3.7 CO_2 Intensity Factors:

CO_2 factors given in Table 19 are based on data from the 1999 "National Greenhouse Gas Inventory" and the marginal emissions factors from the AGO's "Greenhouse Gas Abatement Program" (GGAP), as detailed in the table notes.

Electricity (2001)		**Natural Gas (1998/99)**	
Location	**CO_2 (kg/kWh)**	**Pipeline**	**CO_2 (kg/GJ combustion)**
NSW	0.95	Moomba – Sydney, Adelaide (NSW, SA)	50.8
Victoria	0.99	Longford - Melbourne (Victoria)	50.8
Tasmania	0.01		No Mains Gas
South Australia	1.02	Moomba – Sydney, Adelaide (NSW, SA)	50.8
West Australia – SW (Perth)	1.052	Dampier - Perth (WA)	52.1
		Dongarra – Perth (WA)	51.4
NT – Darwin	0.651	Amadeus - Darwin (NT)	51.7
NT – Katherine	0.650	Denison Trough - Gladstone (Qld)	50.3
Qld North (Townsville)	1.27		No Mains Gas
Qld Central (Longreach)	1.01		No Mains Gas
Qld South (Brisbane)	1.02	Roma – Brisbane (Qld)	52.1
		Australia (weighted average)*	51.4

Table 19: CO_2 Emission Factors for Electricity and Natural Gas

Notes to Table 19
'Australia (weighted average)' is generally used, as it is the most stable over time.
Source: **Natural Gas**: AGO 2001. National Greenhouse Gas Inventory 1999 Appendix A.
Electricity Annual Average Marginal Intensities including Average Region Loss Factors 2005:
http://www.greenhouse.gov.au/ggap/internet/electval.html.
Data source spreadsheet: nswmargintensities.xls. Downloaded: 11 Sept 2001

Although fixed CO_2 emission factors are given in Table 19, the expectation is that these will change over time. Table 20 provides an extract from the GGAP documentation on a five yearly basis. Changes in future generation plant types or fuels, or a Bass Strait cable, would result in significant changes.

State / Territory	2005	2010	2015	2020
Tasmania	0.805	0.809	0.774	0.707
South Australia	0.783	0.810	0.670	0.595
Victoria	0.810	0.807	0.768	0.695
NSW	0.835	0.855	0.831	0.777
Queensland South	0.823	0.853	0.824	0.775
Queensland Central	0.810	0.818	0.794	0.744
Queensland North	0.974	0.798	0.804	0.710

Table 20: Annual Average Marginal Intensities including Average Region Loss Factors

3.8 Appliance efficiencies:

NatHERS, as with many thermal simulation programmes, evaluates only the energy required for the space conditioning (heating and cooling) – the energy which would be consumed by a suitable appliance must be determined by an additional calculation which takes into account the appliance operating efficiency.

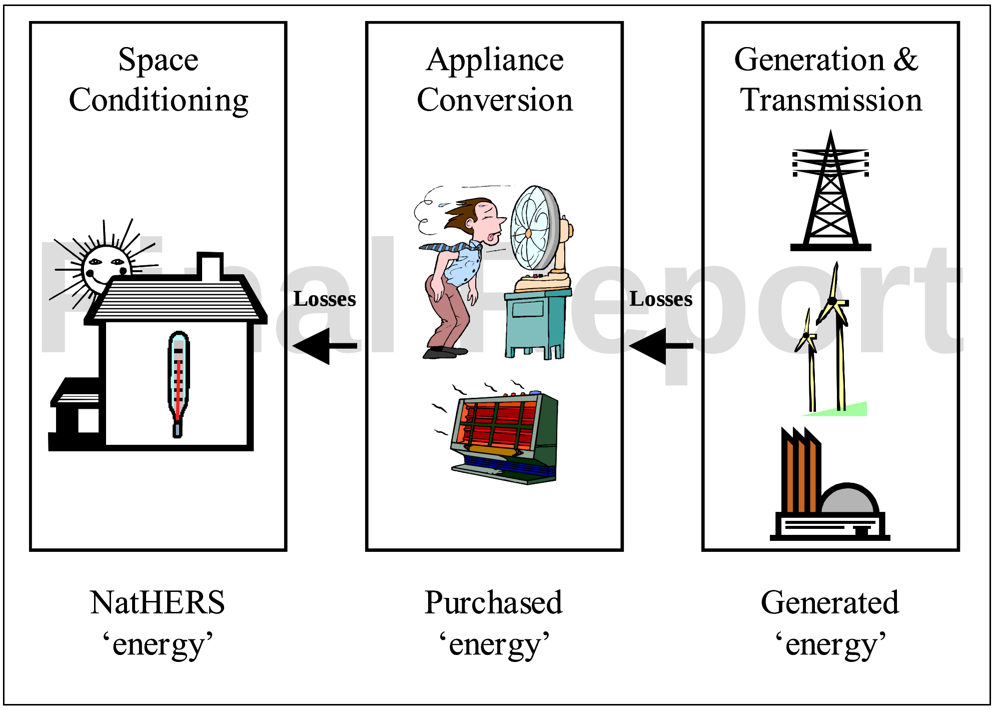


Figure 8: 'Energy' Use

As illustrated in Figure 8, the user sees 'purchased' energy, which in turn is obtained through a transmission system from appropriate 'generation' sources. At each step in this process there are inefficiencies or losses. In order to include consumer controllable losses in the analysis, the financial analysis tool includes both default and user specifiable conversion efficiencies. The transmission and generation inefficiencies have not been considered in this study.

Although there are a wide range of appliances, and operating efficiencies, for the purpose of the analysis tool a range of simplifications have been made. Table 21 lists the appliance conversion efficiencies used in the financial analysis tool. It should be noted, that the user is free to alter these efficiencies as required.

Appliance Type	Efficiency
Electric Air Conditioning	240%
Electric Reverse Cycle (Heating)	270%
Electric Resistance Heating	100%
Gas Heating	61%
Gas Cooling	60%

Table 21: Default Conversion Efficiencies Used in Tool

3.9 Energy rating and CO_2 Emission Savings

Energy rating is expressed in energy consumption per square metre of floor area for the house, expressed as discrete "Star Ratings" from 0 to 5 Stars with half Star steps. The financial tool uses the ratings provided in NatHERS for each location, which are in Megajoules per square metre (MJ/m²) for each climate zone.

There is a direct relationship between energy use and CO_2 emissions for given fuel types, appliance efficiencies, and location. Hence the amount of CO_2 emissions that can be saved by reducing energy use is readily calculated. Star ratings and CO_2 savings are produced as part of the output of the financial tool.

4. MODELLING

For each of the selected houses a ‘model’ was prepared for use in NatHERS by Energy Partners. These were then provided to SEAV, along with details of the energy efficiency options. SEAV prepared a set of NatHERS files with each alternative energy efficiency option and combination. These were then run on one of six desktop computers. Each house model run alternative took approximately 2 seconds.

This section provides background information on the house designs, the occupancy period and presents selected results to illustrate the consequences of incrementally increasing the house envelope thermal resistance.

4.1 House Designs

Figure 9 provides comparative illustrations and floor area data (Gross and Conditioned Floor Area) for the six house designs to scale. Figure 10 provides plan views of the ground floor, not to scale. Full floor and vertical plans are provided in Section 11.2.

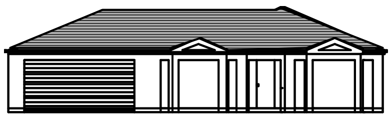
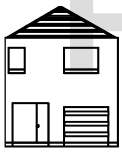
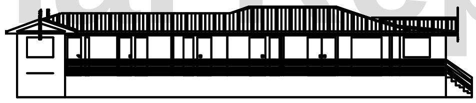
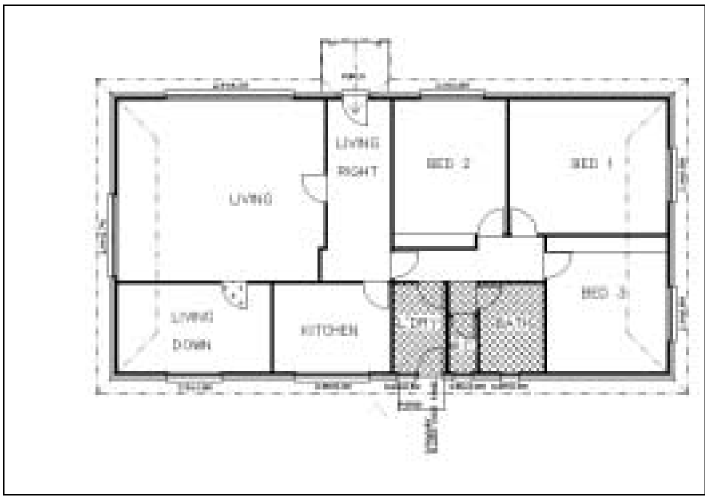
		
House 1: Small Single Storey (173 m² GFA, 143 m² CFA)	House 2: Medium Single Storey (251 m² GFA, 168 m² CFA)	House 3: Large Two Storey (294 m² GFA, 203 m² CFA)
		
House 4: Townhouse (133 m² GFA, 84 m² CFA)	House 5: Cross Ventilated Tropics (156 m² GFA, 138 m² CFA)	House 6; “Passive Solar” (172 m² GFA, 152m² CFA)

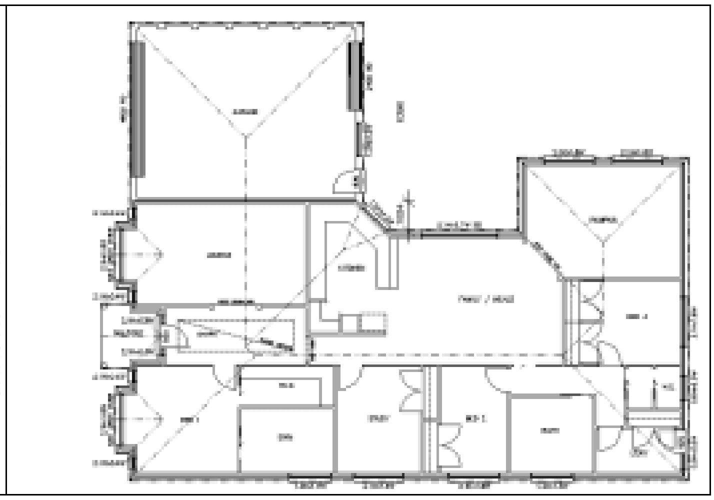
Figure 9: House Designs

For the selected house designs, the ‘front door’ faces north in the base version, except for the ‘Cross Ventilated Tropics’ (House 5) where the verandah faces north, and the ‘Passive Solar’ (House 6) which is orientated east-west. However, as it was not expected that the BCA could require a specific orientation, all houses were modelled facing in all directions. When shading (eaves, awnings or verandahs) was added to the base house design, these were modelled on all sides of the house. It is recognised that this modelling approach will increase the cost of shading against the energy savings and is also unlikely to be followed in the majority of houses, but it provides a conservative result as a basis for the development of future BCA requirements.

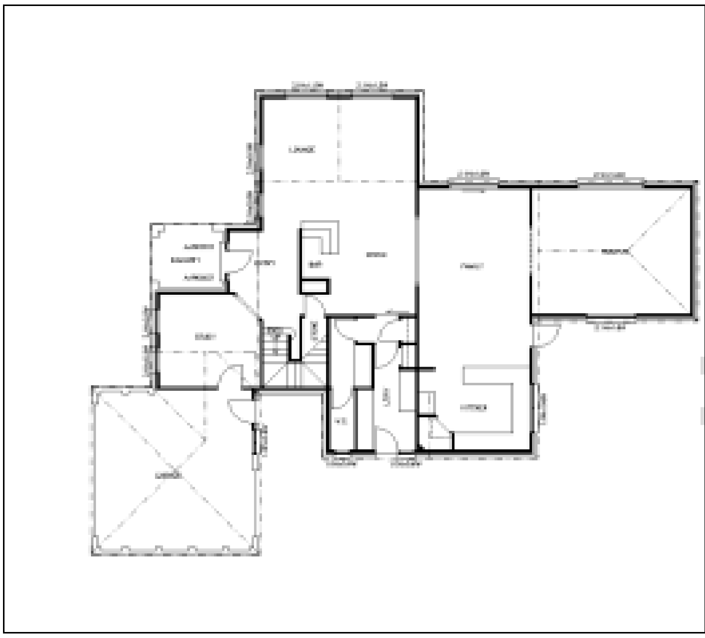
The calculations for House 4 have been found to include some incorrect floor insulation values due to the technique used by NatHERS to model floors with adjacent neighbours, and the accepted method of entering garage walls. An investigation has found that the energy use error caused by this is small.



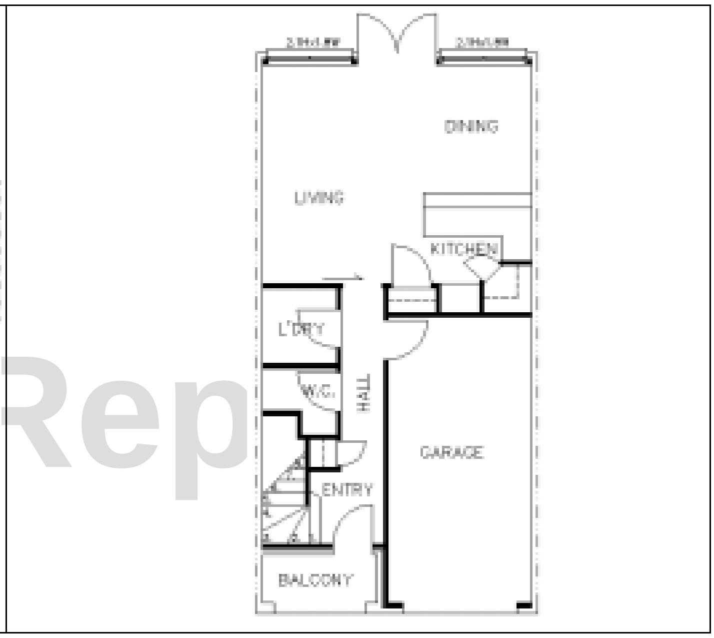
House 1



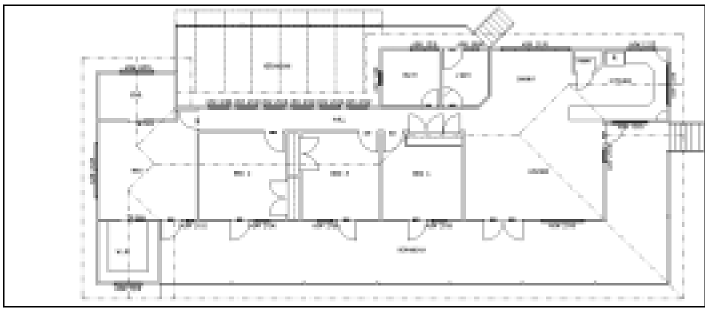
House 2



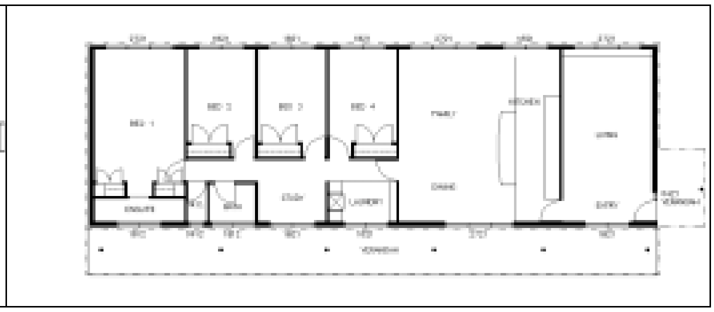
House 3



House 4



House 5



House 6

Figure 10: House Grand Floor Plan Views (not to scale)

4.2 Occupancy

There are a wide range of possible occupancy schedules which could be used as a basis for financial analysis – ranging at one extreme to conditioning for a bare minimum of time (e.g. 7 am to 8 am for breakfast, 6 pm to 10 pm for 'family at home') through to continuous conditioning (24 hours a day). NatHERS assumes an occupancy, and hence a space conditioning requirement, for the time period 7 am to 12 pm – 17 hours per day. These would not appear an unreasonable choice, as a fully conditioned new home is likely to be managed to optimise the comfort of the occupants. The sales of add-in space conditioning appliances suggest that people in existing homes will place a high value on 'comfort' – particularly for appropriate conditions in the summer.

The interim roof insulation RIS (ABCB 2001) references an earlier study which found that "*that many householders are accepting standards of thermal comfort that are significantly lower than those used in NatHERS"* (EES 1999). In the absence of measured data, the RIS set out a range of adjustment factors from 5% for the warm humid climate to 60% for the cool temperate climates. there is a need to ensure that such adjustment factors do provide a realistic representation of the behaviour of the occupants of new homes.

There is no measured data available on the space conditioning practices of new home buyers, but there are limited survey results available of user reported use averaged over all houses. The published information does not support separation of 'existing' and 'new' house appliance use patterns. It is also important to note that these are 'user reported', and not based on monitored appliance use. Table 22 is extracted from the Australian Bureau of Statistics 1985-86 survey of appliance uses (ABS 1988).

The survey found that on average space cooling was reportedly used for 6.5 hours per weekday, with slightly longer use on the weekend. Space heating was reportedly used for 5.1 hours per weekday and an additional 0.4 hours on the weekend.

	Weekday (Average hr/day)		**Weekend (Average hr/day)**	
Fuel : Electric	**Cooling**	**Heating**	**Cooling**	**Heating**
NSW	5.3	5.1	5.8	5.3
VIC	5.6	4.8	5.3	5.5
QLD	8.6	3.4	9.1	3.5
SA	5.7	4.3	4.6	4.6
WA	8.1	4.1	7.6	4.5
TAS	#N/A	7.4	#N/A	7.6
NT	11.7	#N/A	13.7	#N/A
ACT	#N/A	12.3	6.4	13.6
Australia	6.5	5.1	6.6	5.5

Table 22: Household Use of Heating and Air Conditioning (1985-86)

A second occupancy schedule is available through the Financial Analysis Tool. It assumes conditioning 7 am to 9 am, and 5 pm to 11 pm – a total of 8 hours per day. This permits the user to evaluate the sensitivity of cost-benefit outcomes to changes in the value placed on comfort, by varying the price of energy as a surrogate measure.

4.3 Component Thermal Resistance

The thermal resistance of a building component is not a simple combination of the thermal resistance of the individual parts. In particular, account must be taken of parts of the assembly with lower thermal resistance (referred to as 'thermal bridges'). There is currently no Australian Standard for the calculation of thermal resistance, but reference is made to international standards. For example, AS2627.1:1993 references NZS 4214:1977 "Methods of determining the total thermal resistance of parts of buildings", or the ASHRAE Fundamentals Handbook (ASHRAE 1997) can be used.

In general, time limits mean such calculation methods are not used for common building components, the designer referring to some specific calculation. AS2627.1 (Appendix D) provides R-values for a limited number of constructions, while the "BRANZ House Insulation Guide" (BRANZ 1995) provides R-values for a larger number of components.

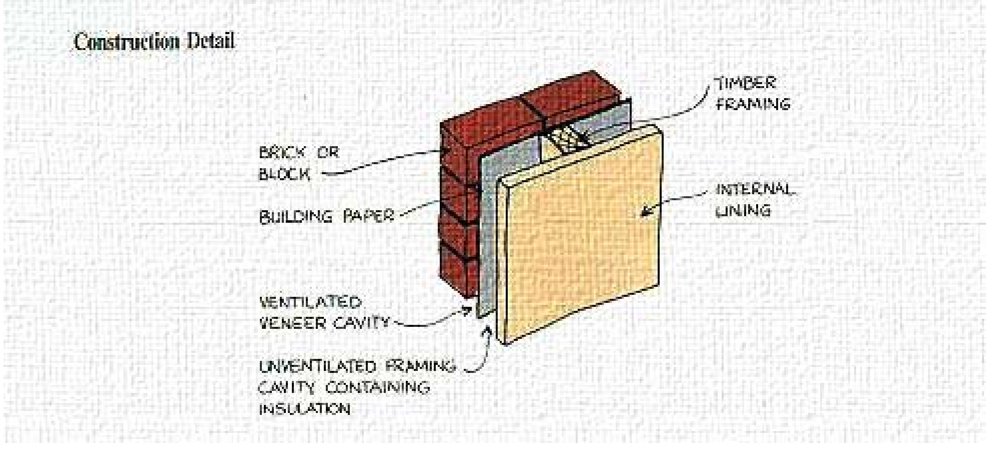


Figure 11: Brick Veneer Wall – Construction Detail

Description	Value of Added Insulation Material Within Framing Cavity							
	Nil	R 1.4	R 1.8	R 2.2	R 2.6	R 3.0	R 3.4	R 3.8
2 Dwangs, Studs 400 mm ctr	0.5	1.4	1.7	2.0	2.3	2.5	2.7	2.9
2 Dwangs, Studs 600 mm ctr.	0.5	1.5	1.8	2.1	2.4	2.6	2.9	3.1
3 Dwangs, Studs 400 mm ctr.	0.5	1.4	1.7	2.0	2.3	2.4	2.7	2.8
3 Dwangs, Studs 600 mm ctr.	0.5	1.5	1.8	2.1	2.4	2.5	2.8	3.0

Table 23: Brick Veneer Wall – Effective R-value

Figure 11 and Table 23 are taken from the "BRANZ House Insulation Guide" and provide the total thermal resistance for a timber framed wall, brick/block veneer, insulation within framing - 150 mm framing using blanket and segment bulk insulants. In this case the framing timber and the mortar between the bricks act as thermal bridges. If steel framing was used, additional thermal separation would be required. To achieve the R-values given in Table 23, building paper must be used as shown in Figure 11. Blown insulants must completely fill the framing cavity. The total R-values in Table 23 also apply when 80 mm or 120 mm bricks or blocks are used.

Added Thermal Resistance AS2627.1 Table 2.2 (m^2 °C/W)	Total Thermal Resistance Wall (m^2 °C/W)	Difference (m^2 °C/W)
1.0	1.3	+0.3
1.5	1.7	+0.2
2.0	2.0	0

Table 24: AS2627.1 'Added' Insulation vs. Total Wall R-value

Table 24 reproduces the table from AS2627.1:1993 which provides a comparison between the 'added' thermal resistance specified in AS2627.1 and the total overall wall thermal resistance for a brick veneer or weatherboard clad wall. The resultant total thermal resistance is similar to those given in Table 23, as the bridging effect of the framing timber results in a reduction in the total overall R-value. AS2627.1:1993 provide a limited series of examples of common wall and roof constructions, and advises the use of NZS4214:1977 for other constructions.

For the purposes of this study, for the NatHERS analysis the overall R-values generated by the NatHERS package have been used. For the other analysis tools (see Section 4.8) the NatHERS generated R-values have been determined and used.

In the future, it will be necessary to provide suitable tools for use by the building industry to ensure the appropriate thermal resistance is achieved in the building component. This will require the use of an agreed Standard. There is an international move to consideration of whole component R-value – this will ensure that not only are the effects of additional thermal bridging (e.g. additional structural timber over doors or windows) taken into account, but also the effects of complex junctions between wall and wall (e.g. corner), floor and wall and roof and wall[viii].

It should also be noted that the R-value does not fully define the thermal performance of a wall system. There are at least four physical attributes of a wall system that must be considered when investigating whole-wall thermal performance: whole-wall R-value; thermal mass benefit; airtightness; moisture tolerance.

For the ABCB "Regulatory Impact Statement 2001-1" (ABCB 2001), minimum pitched roof R-values of R 0.7 m²°C/W were used for upward heat flow (winter heating) and R 1.7 m²°C/W for downward heat flow (summer cooling), while R 1.0 m²°C/W was used for the bulk insulant. These values have also been used in this study. The foil R-values match the values given AS2627.1:1993 (Appendix D) for a tiled roof, reflective foil laminate, gypsum plasterboard which for an upward direction of heat flow the value is given as R 0.73, and for downward heat flow a value of R 1.75.

4.4 Envelope Thermal Performance

Adding thermal insulation to a building component will increase the thermal performance of that component. However there is an interaction between the different components, so it is not possible to determine the energy impact of increasing (for example) the wall insulation and simply add it to the energy impact of increasing (for example) the roof insulation. To understand the overall impact of different energy efficiency options, it is necessary to model each option both separately and in combination. It is therefore necessary to have a methodology of presenting both the impact of each option on the overall envelope thermal performance and the energy usage. This takes the form of the 'area weighted R-value'.

4.4.1 Area Weighted R-value

The overall thermal efficiency of the building envelope is established by the thermal resistance (R-value) of the roof, wall, floor and windows. However, it is not possible to simple add the individual R-values in order to have a single measure of the envelope thermal resistance. It is necessary to calculate an 'area weighted R-value' which takes into account the thermal bridging effect of the areas with lower thermal resistance. For this report, the area weighted R-value is used solely to provide a summary point for the impacts of altering the thermal resistance of different parts of the building envelope.

The area weighted R-value follows the concept of the Overall Thermal Transfer Value (OTTV) which is (or has been) used as a regulatory tool in some countries e.g. Hong Kong and Singapore.

[viii] e.g. the ORNL whole wall R-value calculator: http://www.ornl.gov/roofs+walls/whole_wall/index.html

The area weighted R-value allocates the R-values for each component across the entire building envelope, using Equation 1. Equation 1 incorporates the ability to provide for different roof thermal resistance for the summer and winter, as would be the case for reflective foil laminate.

$$R_{AreaWeighted} = \frac{A_{Surface}}{\frac{A_{Roof}}{E_{Total}} * \left(\frac{E_{Cool}}{R_{RoofSummer}} + \frac{E_{Heat}}{R_{RoofWinter}} \right) + \frac{A_{Wall}}{R_{Wall}} + \frac{A_{Floor}}{R_{Floor}} + \frac{A_{GLazing}}{R_{Glazing}}}$$

Equation 1

where:

$A_{Surface}$, A_{Roof}, A_{Wall}, A_{Floor}, $A_{Glazing}$ = Area of total surfaces, roof, wall, floor and glazing respectively, around the conditioned area (m^2)

$R_{Roof\ Summer}$, $R_{Roof\ Winter}$, R_{Wall}, R_{Floor}, $R_{Glazing}$ = R-value of the Roof in summer and winter, wall, floor and glazing respectively, around conditioned area (m^2 °C/W

E_{Total}, E_{Cool}, E_{Heat} = Energy use in total, cooling and heating respectively (MJ/m^2/year).

4.5 Improving Envelope Thermal Performance

Table 25 and Figure 12 provide an example of two different ways to increase the thermal performance of the building envelope, using the NatHERS model results for on House 1. There are a number of other possible orders for combining the energy efficiency options, but these have not been included on the graph.

Working across Table 25, the first column provides the summary of combinations in the format 'Roof/Wall/Floor /Glazing'. Thus the first case 0/0/0 /1 has no added insulation to the roof, wall or floor and base (single) glazing. The second column describes the situation as each insulation is incrementally increased, with the 'R-value' column providing the area-weighted r-value (units m^2°C/W). The forth column provides the NatHERS generated energy use in MJ/m^2/yr. For the left case, the roof insulation is increased in steps – from the base of no added insulation, firstly foil is added, then this is replaced by R-1 bulk insulant, which is then replaced by R-3 bulk insulation, and so on. Then the additional roof insulation is left constant, and then the wall insulation levels are stepped up until the maximum level is reached. The wall then remains constant and the floor insulation is changed, and finally when the maximum floor thermal performance is reached it is left constant and the glazing thermal performances are changed. The right columns start with changing the glazing, and then the wall, floor and roof.

Combination	Roof	R-value m²°C/W	Energy MJ/m²/yr	Combination	Glazing	R-value m²°C/W	Energy MJ/m²/yr
0/0/0 /1	R0	0.38	614	0/0/0 /1	Single	0.38	614
1/0/0 /1	Foil	0.43	503	0/0/0 /2	Single + Tint	0.38	628
2/0/0 /1	R1	0.43	386	0/0/0 /3	Double	0.41	562
3/0/0 /1	R3	0.46	333	0/0/0 /4	Double + low-e	0.43	550
4/0/0 /1	R5	0.47	320		**Wall**		
5/0/0 /1	Foil+R3	0.47	331	0/1/0 /4	Foil	0.49	469
	Wall			0/2/0 /4	R2	0.50	464
5/1/0 /1	Foil	0.54	243	0/3/0 /4	R2+F	0.50	461
5/2/0 /1	R2	0.55	237		**Floor**		
5/3/0 /1	R2+F	0.56	233	0/3/1 /4	Foil	0.78	444
	Floor			0/3/2 /4	R2	0.97	437
5/3/1 /1	Foil	0.94	215		**Roof**		
5/3/2 /1	R2	1.25	206	1/3/2 /4	Foil	1.43	317
	Glazing			2/3/2 /4	R1	1.51	193
5/3/2 /2	Single + tint	1.25	214	3/3/2 /4	R3	1.90	137
5/3/2 /3	Double	1.68	148	4/3/2 /4	R5	2.07	122
5/3/2 /4	Double + low-e	1.99	134	5/3/2 /4	Foil+R3	1.99	134

Table 25: Energy Consequences of Increasing Component R-values

Figure 12 graphs the data from Table 25. It can be seen that for the same area weighted R-value, depending on whether the thermal performance has been increased through starting from improved glazing or roof thermal performance, different amounts of energy are required to maintain the required indoor temperature regime. For example:

- area-weighted R-value of 0.97 m²°C/W with energy use of 437 MJ/m²/year is achieved by using double + low-e glazing, R-2 bulk insulation plus foil in the walls, R-2 bulk insulation under the floor and no insulation in the roof

- area-weighted R-value of 0.94 m²°C/W with energy use of 215 MJ/m²/year is achieved by the use of foil plus R-3 bulk insulation in the roof, R-2 bulk insulation plus foil in the walls, dropped reflective foil laminate under the floor and single glazed windows

This illustrates that improvements in the thermal performance of the individual components can not be individually determined and then combined in a simple manner to give the resulting reduction in energy use. It is necessary to model each of the various combinations, and then select the optimum results based on either the improvement in energy efficiency, the reduction in greenhouse gas emissions, the financial optimal solution or the lowest capital investment – or any other selection criteria.

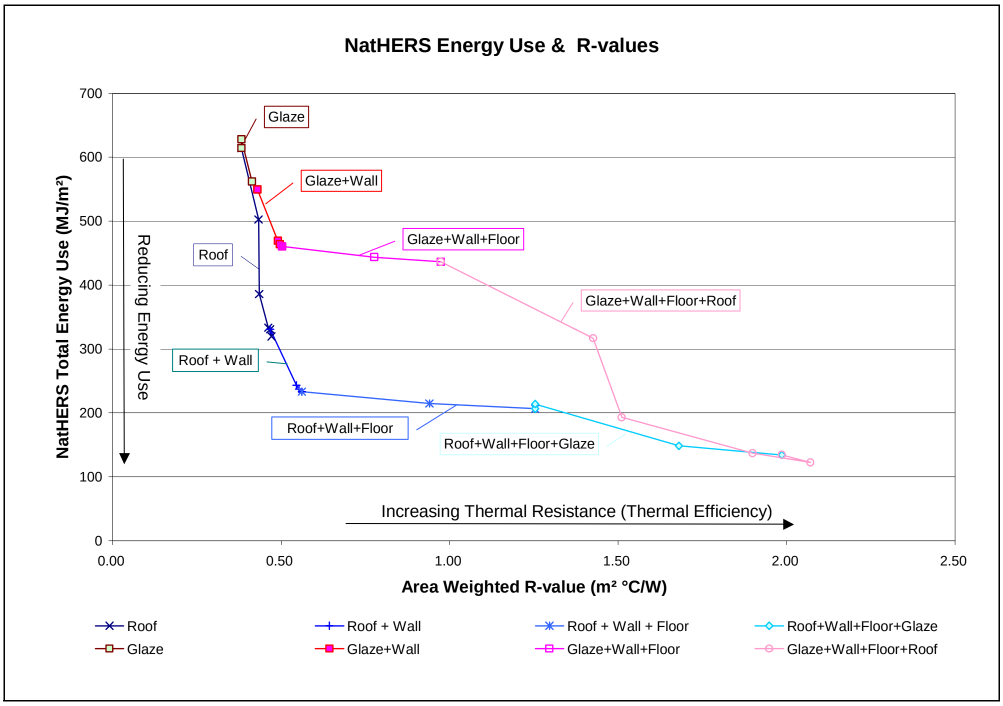


Figure 12: Energy Consequences of Increasing Component R-values

4.6 Model Sensitivity Studies

Additional NatHERS sensitivity studies have been undertaken to investigate the importance of glazing area, occupancy schedule, the use of curtains and blinds, carpet, natural ventilation and infiltration. Table 26 summarises these studies, and the type of investigation undertaken.

Variations	Comment or Definition
Glazing area	Subtract 1 m² from a window (reduce width) to a conditioned area on each of the 4 façades. Where there is choice, subtract from the Living Zone before Sleeping before Other. Where there is no conditioned zone, subtract from the unconditioned Zone.
Occupancy	Make the heating and cooling plant operate continuously with thermostat control.
Curtains and blinds	In Darwin, add Venetian blinds. In West Sydney and Canberra, add drapes with pelmets.
Carpet	Remove Carpet from Living, Bed & Other Zones
Natural Ventilation	Double the ventilation rate only in the Cross Ventilated Tropic house in both calm and breeze conditions.
Infiltration	Add an Exhaust Fan w/o Damper to the Base house. Add weatherstripping to the Satisfy and Min CO_2 houses.

Table 26: Sensitivity Studies

The sensitivity studies were undertaken on three house types: House 2 (Medium single storey), House 3 (Large double storey) and House 5 (Cross ventilated tropics), for three climates: Darwin (hot), West Sydney (temperate) and Canberra (cool). Three variations in energy efficiency options were used: Base House, Mid Range of Energy Efficiency options; and Options achieving maximum CO_2.savings with a positive NPV under base assumptions.

A separate investigation has been undertaken into issues of thermal insulation in tropic climates where air conditioning is not used. The results from these studies are reported in Section 6.

4.7 Detailed Comparison Study for Foil Insulation in Roofs

At the outset of this study, it was recognised that the simulation of foil insulation in other than a vertical installation as in walls was relatively simplistic in NatHERS. The program allows only one R-value for the installation while the actual thermal resistance is significantly different depending on whether the heat is flowing downward (where the dominant heat transfer mechanism is by surface-to-surface radiation) and upward (where convection is a substantial heat flow mechanism). NatHERS uses the lower of the two values – the R-value for upward heat flow which is dominant in winter – being 0.46 $m^2°C/W$. In the case of tiled roofs it also allows for the quasi-insulating benefit of reducing the infiltration rate in the roof cavity or attic space.

To make allowance for this weakness, special additional simulations were undertaken manually in which the performance of the foil with the heat flow down was estimated by using the combination of foil and R-1.0 bulk insulation under the roof, resulting in a total added insulation of 1.46 $m^2°C/W$ to the underside of the roof[ix]. The pairs of results (heating and cooling for House X in Climate Y) were then merged by taking the cooling results (both sensible and latent) for the “downward” simulations and the heating results for the “upward” simulations as an estimate of the year round performance of a house with foil in the roof.

Equivalent simulations were also undertaken by Luminis Pty Ltd (University of Adelaide) using the EnCom2 software which more specifically deals with this heat flow simulation problem, but also used separate model runs to evaluate the winter and summer space conditioning requirements. The EnCom2 program[x] is being continually developed by Dr Terry Williamson of the University of Adelaide for research purposes. It is not commercially available. It has no user-friendly front end and hence needs a high skill level of its operators but it is respected for its articulation of building physics nuances like directionally sensitive heat flow resistances which are calculated on an hour-by-hour basis in its computation routines.

It was found initially that the two programmes gave significantly different results, particularly with respect to the EnCom2 cooling energy use. A workshop was therefore convened in the Melbourne offices of CSIRO on 24 September 2001 to examine and discuss the first results, and to seek out points of difference in both the constructed models of each of the six dwellings and in the algorithms used by the programs themselves. The workshop was chaired by Trevor Lee of Energy Partners on behalf of the project team and was attended by the four key personnel in this part of the comparison study:

- Helen Bennetts, Luminis Pty Ltd, skilled user of EnCom2
- Angelo Delsante, CSIRO, expert in NatHERS software
- David McCook, Energy Partners, skilled user of NatHERS
- Terry Williamson, University of Adelaide, expert in EnCom2 software

In the analysis and discussion of the models and algorithms to be harmonized for this exercise, the following points were established as set out in Table 27. It should be noted that the direct use of the CHENATH simulation programme (see Section 1.2) directly would have enabled a finer control over the models than was possible by the use of NatHERS.

The differences noted in the six dwelling models were corrected prior to the further simulations in the major comparison study (see Section 4.8) and, where practical, improvements were to made to the software for that same purpose. Some potential improvements to NatHERS were also noted but it was recognised that they would require specific-purpose funding and hence would not be available for the comparison study of this project.

[ix] $\Sigma R = 0.46 + 1.00 = 1.46\ m^2°C/W$

[x] EnCom2 is based on early programming work by Beth and Alan Coldicutt, University of Melbourne.

The modified numerical results from the NatHERS and EnCom2 RIS modelling are tabulated in Section 12.2.

EnCom2	**NatHERS (or its 'engine' CHENATH)**
Solar Radiation Data Same as NatHERS	Takes its time zone from the entered state (but its climate zone from the postcode) The solar irradiance read from the weather data file on the hour (clock time) is treated as an instantaneous value, and is assumed in the simulation to change linearly from one hour to the next. However, the value in the weather data file is actually the sum of two half-hourly solar irradiation values (measured at solar time). The two half-hourly values were chosen so that their mid-point aligns as closely as possible with the hour (clock time).
Exterior and Interior Roof Absorptance & Emissivity A = 0.7 - Variable – to be set to 0.5 to match (manual suggests 0.5, 0.8, 0.9 for dirty roofs) For underside of metal deck roofs (zinc/aluminium/steel) value assumed in initial simulations E = 0.5 Value set to E=0.9 to match NatHERS	A = 0.5 Mid colour (0.8 dark, 0.25 light) E = 0.9 (independent of roofing)[xi]. The outdoor emissivity can be set to any value in the CHENATH engine. The indoor emissivity cannot be set directly. Special modifications to the CHENATH input data file SCRATCH are needed to properly handle low-emissivity roofspace surfaces.
Roof Space or Attic Assumed undivided for houses studied but may be divided to reflect actual construction/design Heat flow through attic roof space the subject of explicit calculation taking the attic as a zone. Roof area calculated from input roof geometry Roof volume input from hand calculation	Assumed undivided (but CHENATH can divide into zones) Adds R0.46 for foil (heat flow up) Reduces infiltration factors for tiled roofs[xii]. Any value can be added in CHENATH. Roof area assumed 1.19 x ceiling area Roof volume assumed 1.05 x roof area[xiii] (but CHENATH can accept house-specific values)
Wall Absorptance Variable – to be set to 0.5 to match NatHERS	Mid colour = 0.5
Sub-floor Ventilation for Cross Ventilated Tropics Used a large volume of 330 m³. Ventilation rate may be varied but set at ACH = 4 + 12 x Windspeed based on air changed measurements of similar houses.	Can use CHENATH and set subfloor = ambient Used a volume of 75 m³ with 200 ACH[xiv] which averages about 1,500 m³/hour
Windows Area = area of structural opening U-value may be varied but set at value 5.5 W/m²K and adjust for wind speed. Value taken from NatHERS output as the average glass plus frame value. Solar aperture = Area. (Note: EnCom2 has been revised to consider Solar Aperture = 95% x Area) Reduce internal film resistance for air movement – e.g. fans or evap-cooler	Area = area of structural opening Set design U-value of 5.5 W/m²K (90% glass at 4.7, 10% aluminium frame at 12.7) and adjust for wind speed (the range of U-values is output by CHENATH but not reported by the NatHERS report) Solar aperture = 90% x Area Frame absorptance = 70% Reduce internal film resistance for air movement – e.g. fans

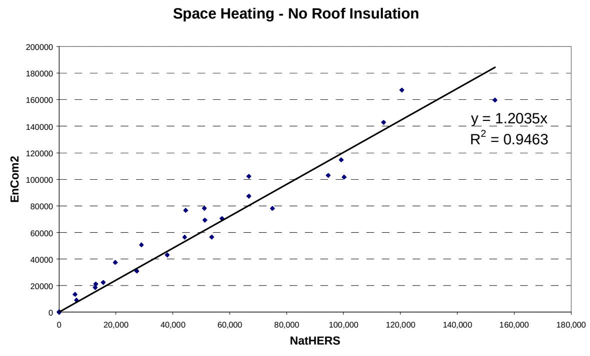
Table 27: Thermal Analysis Conventions - NatHERS and EnCom2 Compared

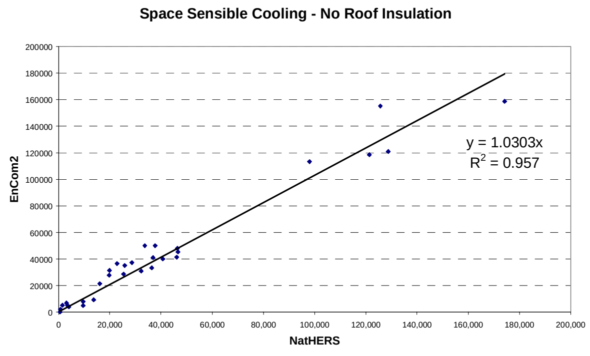
[xi] Linear interpolation from Hassall (1977) suggests that a change to E = 0.5 will add R 0.24 m²°C/W(down) and R 0.13 m²°C/W (up) in the absence of foil.

[xii] Tiles only: Infiltration (air changes per hour) = 6 + 2.5 x √Wind Speed (m/sec)
Tiles + foil: Infiltration (air changes per hour) = 2 + 1.0 x √Wind Speed (m/sec)

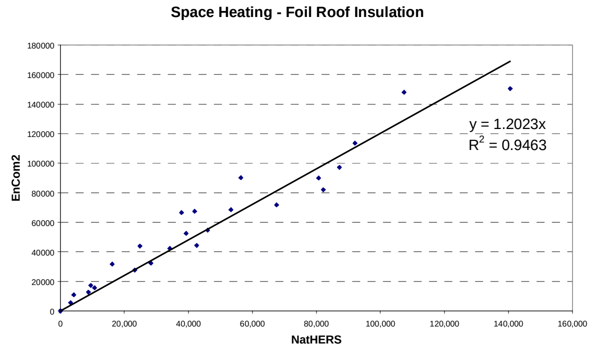
[xiii] Derived from measurement by Steve Moller of A V Jennings' "Hollywood" 175 m² GFA house.

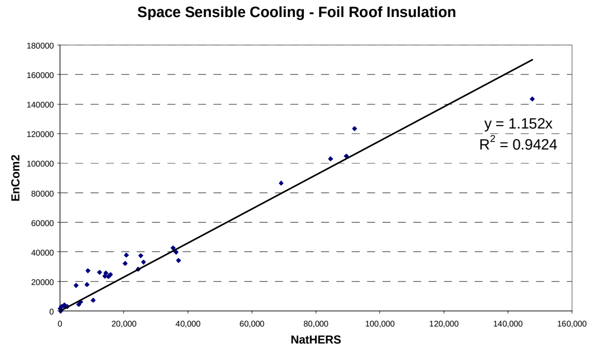
[xiv] It appears likely that this will have been constrained in the simulation to 40 ACH as applies to internal areas to account for that fact that CHENATH calculates an environmental temperature, not an air temperature.



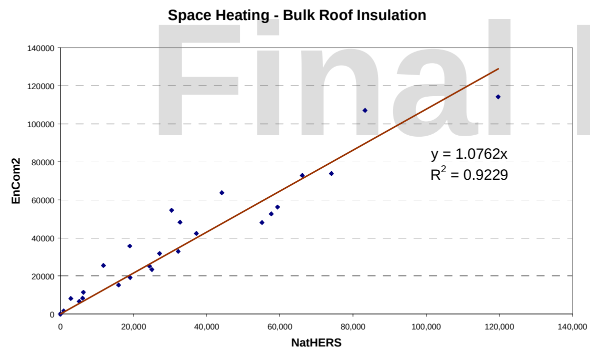


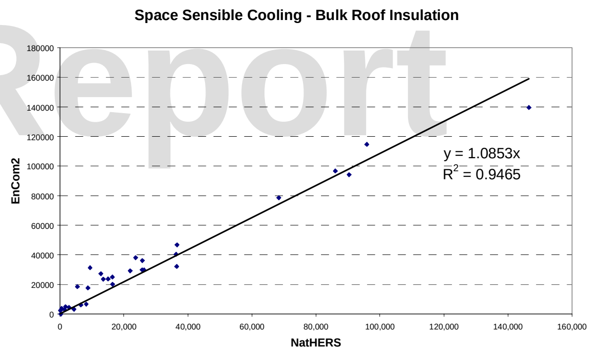
No Roof Insulation





Roof - Reflective Foil Laminate





Roof – Bulk Insulation

Figure 13: Space Heating Comparison

Figure 14: Space Cooling Comparison

Figure 13 and Figure 14 provide a comparison of the total space heating and space cooling energy requirements respectively for houses (reading vertically downward) with no roof insulation, reflective foil laminate and R 1 bulk insulation. If the NatHERS and EnCom2 model outputs were exactly the same, the relation would be of the form Y= X. The regression equations given on each graph (forced to have a y-intercept of zero) show that the relationship is reasonably close (with the EnCom2 results around 20% higher for space heating energy, and 10% higher for cooling energy).Figure 15 compares the difference in heating energy use (the difference between the base case and the case with either foil or bulk insulation) per unit area for the six houses over the five climates, while Figure 16 provides the same comparison for the difference in cooling energy use. It can be seen that the relationship between the EnCom2 and NatHERS models are closer for the space heating than for the space cooling. Note that the comparisons given here deal only with sensible cooling (see Section 1.2). The differences between the two programmes for the modelled energy use for House 5 (Cross Ventilated Tropics) have been explored, and are not able to be resolved within this contract.

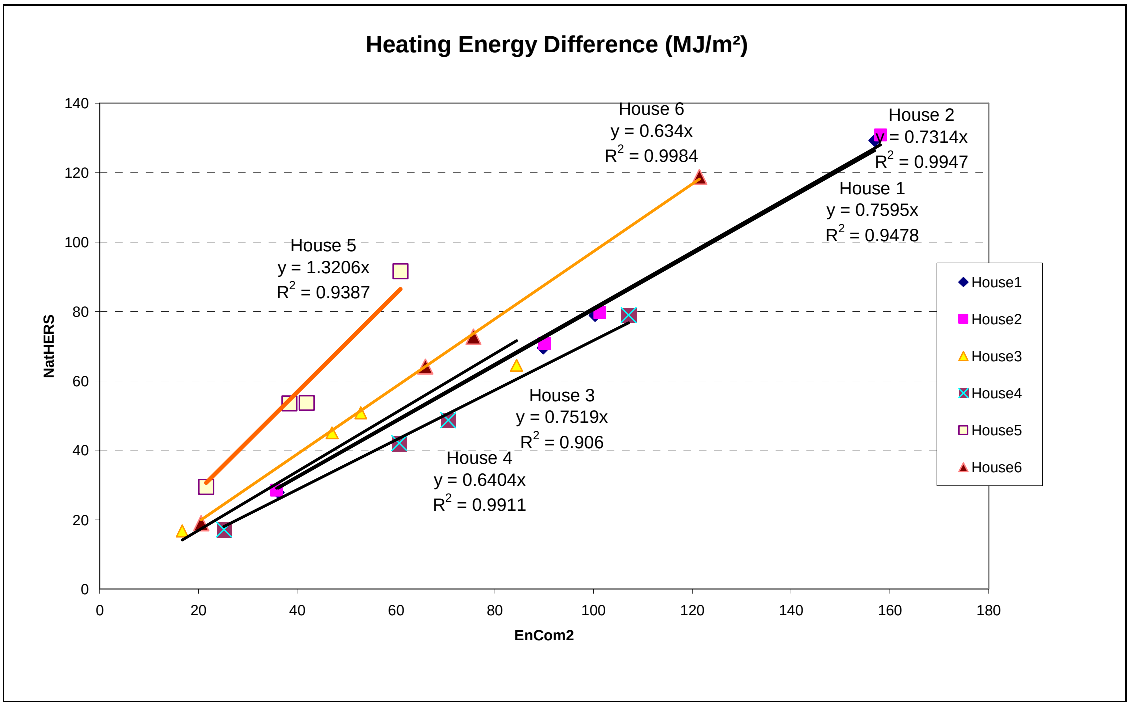


Figure 15: EnCom2 vs. NatHERS – Heating Energy Difference

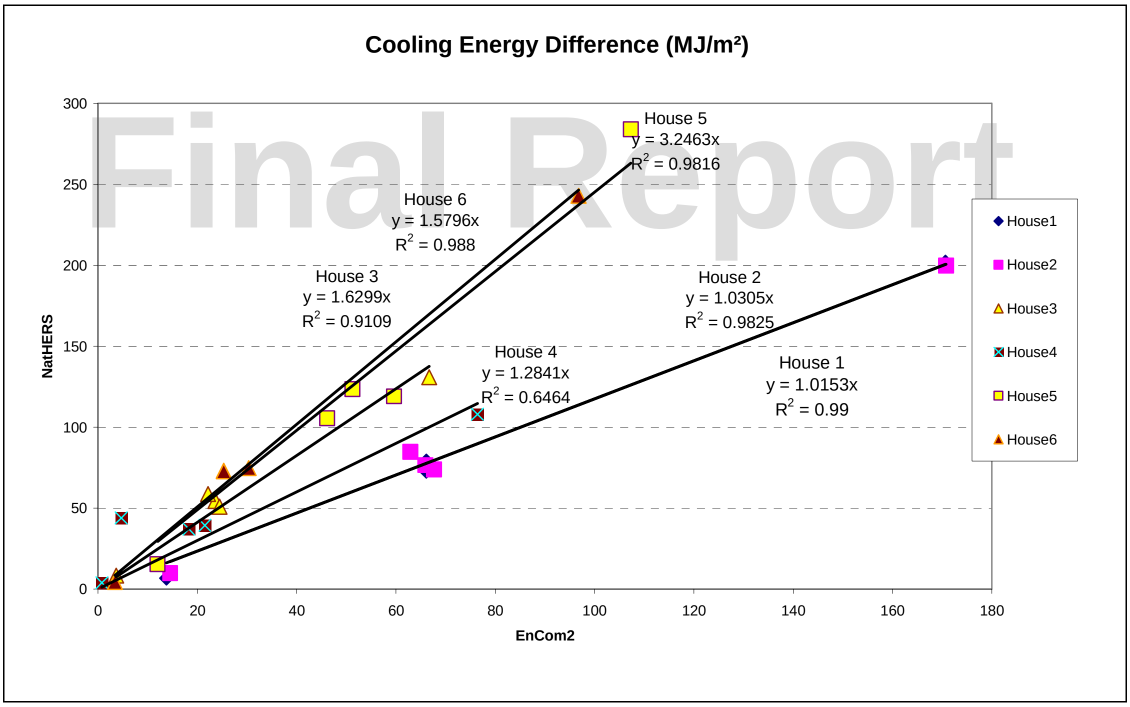


Figure 16: EnCom2 vs. NatHERS – Cooling Energy Difference

4.8 Other Thermal Simulation Programmes

DOE2 model runs were commissioned from Dr Steve Szokolay, University of Queensland and **EnCom2** model runs from University of Adelaide.

DOE2 is an internationally recognised and validated thermal simulation programme, more attuned to the fully air conditioned houses of hot climates. It was used to develop the previous Australian Commercial Building Energy Code, but more importantly has been used throughout the world to develop building energy codes (Eley et al. 1994).

For each of the two alternative thermal simulation programme, a model of each of the six houses has been prepared The base case and two variations have been modelled, as given in Table 28:

- **Base House** – no additional insulation
- **Insulated House** – base model with nominated insulation levels in the walls and roof/ceilings in the table below.
- **Maximum CO_2 Saving House** – the base house with the insulation, shading and glazing scheduled in the table below.

The first four houses (Numbers 1-4) were modelled with brick veneer walls and slab-on-ground concrete floor, the cross-ventilated house (Number 5) is open undercroft with a timber floor and weatherboard walls, the Passive Solar houses (Number 6) is cavity brick wall and slab-on-ground concrete floor. The 'eaves' and/or 'verandahs', and floor coverings are as for the NatHERS house files.

Type / Characteristic	Roof/ceiling	Walls*	Floor**	Glazing	Shading
Base house	nil	nil	nil	single/alum.	nil
Insulated base	R1.0	foil (foil)	nil (nil)	single/alum.	nil
Max CO_2 saving	R5.0	R2.0 (50mm)	nil (R2.0)	double/PVC	600 eaves

Table 28: Schedule of thermal characteristics for modelling

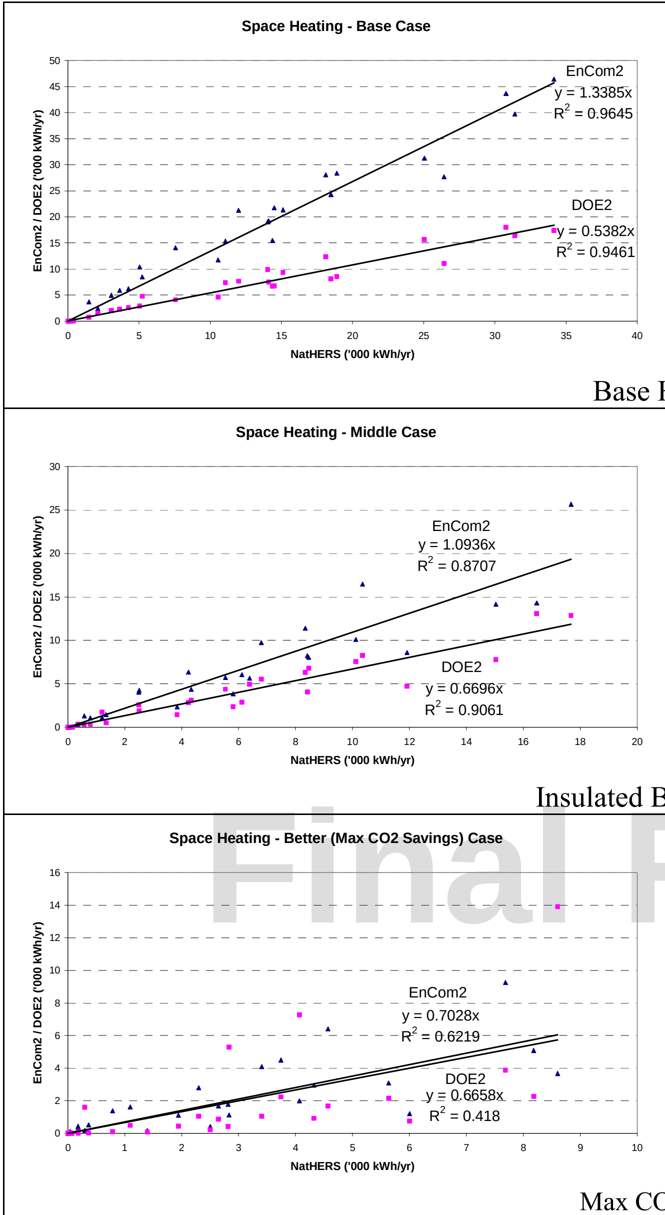
Notes to Table 28
* denotes for brick veneer and weatherboard (cavity brick in brackets – thickness = polystyrene)
** denotes for floor slab on ground (suspended timber in brackets)

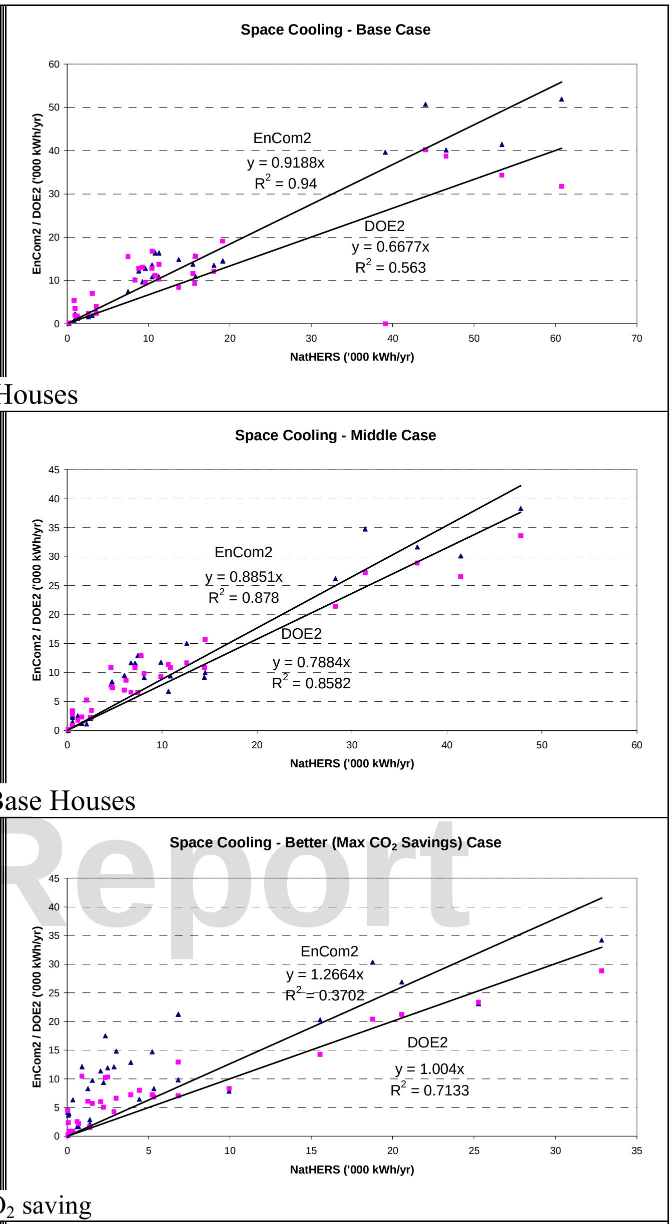
This gives a total of 3 variations for each of the 6 houses (18 model runs) for the five climate zones – a total of 90 model runs.

House	Wall	Floor	Bare	Mid	Better
1	Brick veneer	concrete	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/R2/nil 3/2
2	Brick veneer	concrete	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/R2/nil 3/2
3	Brick veneer	concrete	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/R2/nil 3/2
4	Brick veneer	concrete	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/R2/nil 3/2
5	Weatherboard	timber	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/R2/R2 3/2
6	Cavity brick	concrete	R0/R0/R0 1/1	R1/Foil/R0 1/1	R5/50 mmP/nil 3/2

Table 29: House Variations for Comparison

Table 29 lists the house variations for the NatHERS model runs used for comparison. It should be noted that the modelling of buildings for thermal simulation is not an exact science – there are a large number of inputs required, and the assumptions made by each individual modeller may legitimately be different. This can result is apparently different energy use, so it is necessary to carefully consider consistency – do the simulation outputs tend in the same direction in a similar manner. For example does the heating energy requirement increase with both cooler climate and house size. The following graphs must be read in such a manner.





Base Houses

Insulated Base Houses

Max CO_2 saving

Figure 17: Simulation Comparison - Heating

Figure 18: Simulation Comparison – Cooling

Figure 17 and Figure 18 provide comparisons of the total space heating and cooling energy requirements. The NatHERS generated values are used as the x-axis, and the EnCom2 (triangle marker) or DOE2 (square marker) values as the y-axis. Linear regression lines (forced to intercept at zero) have been fitted to both the EnCom2 and DOE2 results, and are given on each graph along with the coefficients and r-squared values.

Note that the axes coverage change with increasing energy efficiency – the space heating energy requirement almost halving for each graph from the 'base' to the 'insulated' to the 'Max CO_2', but the same is not true for the cooling energy requirement, which only halves from the 'base' to the 'Max CO_2' cases.

	Base	Insulated Base	Max CO_2
Heating (see Figure 17)			
EnCom2 – coefficient	1.34	1.09	0.70
DOE2 – coefficient	0.54	0.67	0.67
EnCom2 - r^2	96%	87%	62%
DOE2 – r^2	95%	91%	42%
Cooling (see Figure 18)			
EnCom2 – coefficient	0.92	0.89	1.27
DOE2 – coefficient	0.67	0.79	1.00
EnCOm2 - r^2	94%	88%	37%
DOE2 – r^2	56%	86%	71%

Table 30: Simulation Comparison - correlations

Table 30 lists the coefficients and r-squared regression coefficients from the linear least-squares regression lines in Figure 17 and Figure 18. The r-square values decrease with the higher levels of energy efficiency for both the heating and cooling cases. This study has not closely investigated the differences in the results, although as discussed in the previous section,

The results comparing the outputs of the three energy simulation programmes reports in this and the previous section, provide additional certainty as to the values used in the financial analysis tool. The three programmes show a reasonable correlation, although the variations in the reported space heating and cooling energy requirements have not be fully investigated. It is recommended that if it is intended to permit more than one simulation programme to be used to demonstrate compliance with a further BCA energy efficiency requirement that additional investigations be undertaken.

5. FINANCIAL ANALYSIS

5.1 Analysis approach

A cost benefit analysis approach was adopted, using the present value methodology. This enabled the identification of financial solutions that maximised energy or CO2 savings whilst remaining cost effective. In addition there was a requirement to be able to identify low energy use solutions, and CO_2 emission savings, and to trade these off against financial savings. A financial analysis tool was developed, combining present value methods with data on CO_2 emission savings, and house energy rating, with the energy consequences evaluated by NatHERS for various energy efficiency combinations.

5.2 Financial analysis

The present value method was used, in which costs are brought to current dollar values using discounting methods. Two main categories of costs were included:

- **Initial costs**: The costs of insulation, special glazing, and shading.
- **Energy costs:** The on-going costs of energy consumption within the dwellings. These costs are discounted to present values in recognition of the time value of money.

The energy consumption within a house varies for each combination of insulation, glazing and shading and there is a trade-off between initial expenditure on insulation, and on-going expenditure on energy. The present value method allows these trade-off to be quantified in a consistent manner. The formula used is given in Equation 2:

$$PV_{Total} = \$_{Insulation} + PV_{Glazing} + PV_{Shading} + \sum_{t=1}^{n} \frac{(1+e)^t P_o}{(1+r)^t}$$

Equation 2

where:

$\$_{Insulation}$ = Cost of insulation. (i.e. cost of installation + cost of materials)

$PV_{Glazing}$ = The additional initial costs of glazing options, additional to ordinary glazing. For double glazing, the replacement of the window is at 30 years (default, can be changed) and this replacement cost is discounted by the SPPWF (Single Payment Present Worth Factor), as shown in Equation 3:

$$\mathrm{PV_{Glazing}} = \$_{\mathrm{Double\,Glazing\,Premium}} \times (1 + \mathrm{SPPWF}(r, 25))$$

Equation 3

$PV_{Shading}$ = The costs of the shading options, additional to no shading. The full cost of options, 600 mm eaves, awnings, and 3.6 m wide verandahs, was included. For awnings only, a default 25 years lifetime has been assumed, and the discounted replacement cost included in the present value, as given in Equation 4:

$$\mathrm{PV_{Awnings}} = \$_{\mathrm{Awning}} \times (1 + \mathrm{SPPWF}(r, 15))$$

Equation 4

P_o = Initial energy cost.

r = discount rate

e = energy price real escalation (i.e. the rate of escalation above the general inflation rate).

t = time period of the analysis (t = 1, 2,3,……n)

SPPWF(r, T) =Single Payment Present Worth Factor, at discount rate r, at year T.

n = period of analysis. The number of years over which energy savings were discounted.

For a given house, in a particular climate and cost zone, the present value can be calculated for all combinations of insulation, glazing and shading, and the combination with the lowest present value is the optimal combination from a financial viewpoint. It is often useful to present results in terms of Net Present Value, where the base case is the zero combination i.e. no insulation, plain glazing and no shading. In this report, and the financial tool, both values are used.

To rephrase and repeat as Equation 5:

$$PV = \$_{Insulation} + \$_{Additional\ Glazing} + \$_{Shading} + \$^{n}_{Discounted\ Energy\ Costs\ over\ n\ years}$$

Equation 5

The Net Present Value is defined as the difference between the Present Value for the base case (zero insulation, plain glaze, no shade) and the Present Value for the case under consideration with the specific combination of energy efficiency options as given in Equation 6:

$$NPV_k = PV_{Zero\ Insulation, Single\ Glazing, No\ Shading} - PV_{Energy\ Efficiency\ Combination\ k}$$

Equation 6

The combination with the lowest PV and the highest NPV are identical, and give the highest financial return over the life of the building. However, all measures with a positive NPV are cost-effective under the given financial assumptions (e.g. discount rate, lifetime etc).

5.2.1 Discount and Lifetime Defaults

A literature survey undertaken for the AGO and the ABCB provided an extensive historical review of the economic analysis methodology used in the development of building energy codes throughout Australia and New Zealand (Hes 2000). In addition, the ABCB Economic Evaluation Model (ABCB 1997) provides guidance on the approach taken by the ABCB. During the term of this study, the ABCB released the "Regulatory Impact Statement 2001-1" (ABCB 2001) detailing potential energy efficiency measures for services and interim roof insulation for houses.

To convert the nominal discount rate *n* to the real discount rate *r* to allow for inflation *i*, Equation 7 is used (ABCB 1997):

$$r = \frac{1+n}{1+i} - 1$$

Equation 7

From a dwelling owner's perspective, it is logical to view the capital cost of built in energy measures as an increase in capital borrowings and hence an interest cost. Thus assuming a fixed interest rate of 7.5% (which in fact will only be fixed for 5 years) and a CPI inflation rate of 2.5% (Jack Bramwell, pers. com. 10 October 2001) gives a discount rate of 5%. From a social perspective, the discount rate should reflect society's preference to consume now rather than later, which can be measured by the ten year government bond rate because this is the rate that just overcomes this preference. Currently, the 10 year bond rate is about 5.5% nominal and over the past 10 years has averaged 5% real. From an industry perspective, the discount rate should equate to an opportunity cost of investing in energy efficiency rather than elsewhere. This can be approximated by using the average before-tax rate of return for the Australian corporate sector, which is estimated at 5%. Is this correct? It seems a low return. ICP.

The “Regulatory Impact Statement 2001-1”, used a discount rate of 5% and the financial analysis provided for periods of 25 years and 50 years. The former is intended to present financial outcomes from a private perspective, the latter from a longer term social perspective (ABCB 2001). The default discount rate has thus been set at 5% in the analysis tool, and the default analysis period set to 40 years, as intermediate value. All defaults can be altered by the user, as required.

5.3 Economic Analysis

It should be noted that the financial analysis omits some costs that would be included in a full economic analysis. For example the following have not been included:

- **Appliance capital and maintenance costs:** A recent consultants study for SEAV examined the effect of energy efficiency on plant size and the extent of savings in heating and cooling plant due to more efficient design. It compared 2 and 5 Star versions of 3 houses, and extracted load predictions of NatHERS to determine plant size. Standard industry sizing matched the NatHERS peak load prediction for the 2 Star houses, but was typically 50% too big for the 5 Star houses. In ducted gas heating plant savings of up to $1,000 were identified. These are higher for combined heating and cooling systems. The 5 Star houses also achieve almost air conditioned comfort in summer with just ceiling fans. The study has also identified that further savings would have been possible if industry had a better range of products at sizes more suited to 5 Star houses, and that current industry sizing techniques were inadequate for efficient houses (Energy Efficient Strategies 2001). Appliance maintenance costs, which may vary with capacity, also have not been considered.

- **Replacements of special glazing and shading:** Replacement period at years 30 and 25 (double glazing and awnings respectively) have been assumed. However subsequent replacements, and any maintenance costs have been ignored.

- **Multiple benefits of energy efficiency options:** The full cost of the energy efficiency options have been evaluated against the energy savings. In many cases the energy efficiency option will have other benefits. For example, eaves and verandah greatly assist in weathertightness around windows and doors, they may be used for clothes drying, they may form an important ‘outdoor’ space for enjoyment when temperatures are high or rain is heavy, and verandahs provide a transition area into the house in the wet season.

- **Health benefits:** Warmer indoor temperatures in cold areas, and reduction in temperature swings in both cool and tropical regions can result in improve health status for occupants.

- **Moisture control**: Thermal insulation results in higher surface temperatures in cool locations, reducing the opportunities for mould and other moisture related problems

Further examples of non-energy benefits of energy efficiency from the perspective of housing landlords are given in Ward (1994).

It is possible to explore some of these issues with the analysis tool, and a limited range of sensitivity investigations are discussed in Section 5.8.

5.4 Evaluating R-value Requirements

The rest of Section 5 provides a background to the financial analysis used in this report. However, international experience in the use of Present Value analysis for evaluating appropriate levels of thermal insulation has found that the PV curves are often very shallow and hence a wide range of thermal resistance levels are possible for any given set of assumptions.

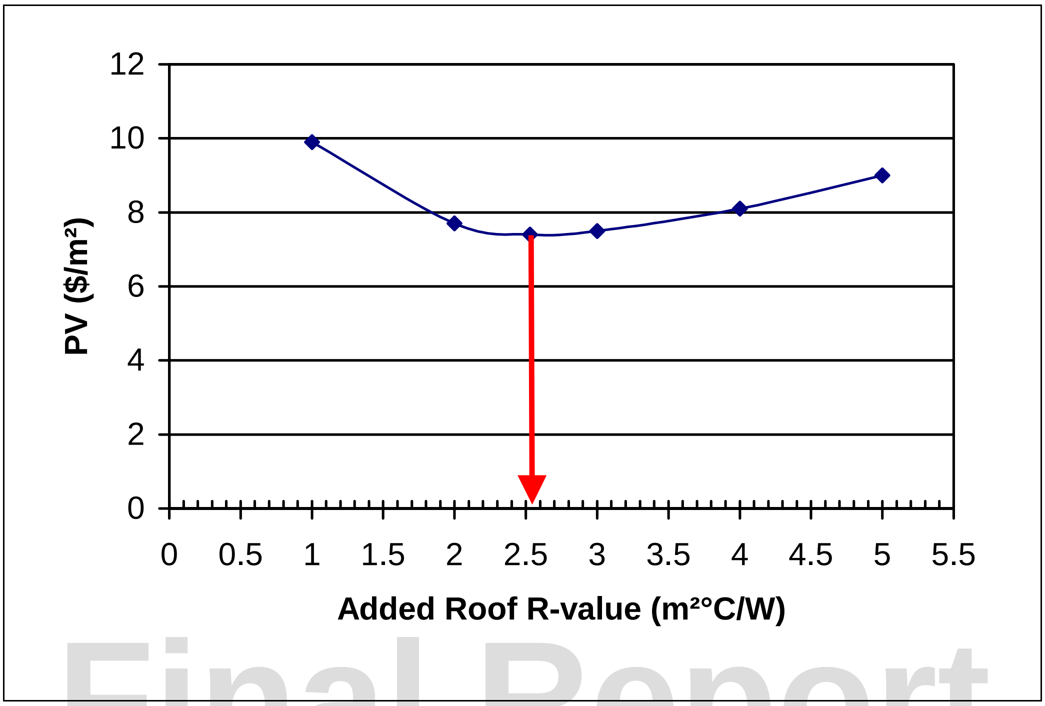


Figure 19: AS2627.1 Economic Optimisation – Melbourne Roof

Figure 19 takes data provided in AS2627.1 : 1993 (Figure B2 for Melbourne), and demonstrates the PV analysis of the benefits of 'additional' thermal insulation in the roof or ceiling over a heated or cooled space for a house located in Melbourne. It can be seen that the curve is shallow, and in this case the minimum PV is achieved for 'additional' insulation of R 2.53. It is clear that a small shift in the assumption behind the calculation (e.g. reduced discount rate, energy use patterns, energy prices etc), a relatively large change could be expected for the minimum NPV. Table 31 illustrates this by comparing the minimum PV with the changes from a small change in the PV.

Table 31 lists the AS2627.1 'Optimum' R-value, the 'optimum' PV and the effect on the R-value of a shift of 30 cents in the PV. For example, for Melbourne a change of 30 cents (a 4% increase in the PV) would suggest an 'additional' R-value of between R 2.0 (a 20% reduction) and R 3.4 (a 36% increase). The variation in R-values for the other two locations are similarly wide. AS2627.1 recognises this by constraining the increment size of the recommended thermal resistance to 0.5 m²°C/W steps e.g. for a calculated R-value of between R 1.25 and R 1.74, the recommended R-value is given as R 1.5.

Location	'Optimum' R-value	PV $/m²	PV + $0.30		'Lower' R-value		'Higher' R-value	
Adelaide	2.0	$6.00	$6.30	+5%	1.4	-30%	2.7	+35%
Melbourne	2.5	$7.40	$7.70	+4%	2.0	-20%	3.4	+36%
Sydney	1.6	$4.90	$5.20	+6%	1.2	-25%	2.4	+50%

Table 31: AS2627.1 Financial Optimisation

This suggests that although it is always possible to determine a minimum PV for any given set of assumptions, there may be a very wide range of possible thermal resistances which would very closely meet the requirements. This has resulted in the inclusion of the ‘Max Star Rating’ evaluation (see Figure 23 for further discussion) in the financial analysis tool.

5.5 Financial Analysis Tool

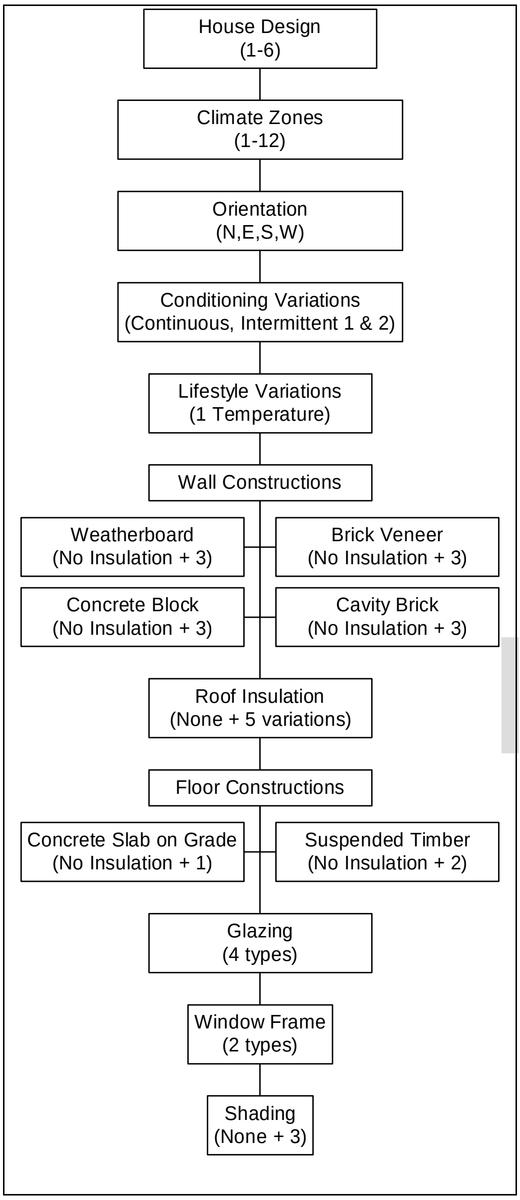


Figure 20: Modelling Variations

The financial modelling tool runs in Excel 2000 under Windows. The programme obtains data from an MS Access dataset. The data includes all insulation combinations for six houses in 12 climate zones, with both 17 hours and 8 hours of conditioning. The programme file size is approximately 3.6 MB, and the Access dataset 36 MB in size. Once ‘zipped’, the files reduce to approximately 3.1 MB and 16 MB respectively. On a 500MHz PC, with 128MB RAM, the file takes about 30 seconds to load, and once loaded the menu selections appear with a delay of a few seconds. (Note however the operation which calculates insulation combinations (“Max Star Rating”) for all climate zones, takes about 3½ minutes to run.). Additional memory, or a faster computer, will further speed the analysis.

As illustrated in Figure 20, for each combination of:

- house type (6 types),
- climate zones (12 types),
- orientation (4 types),
- wall type(4 types),
- glazing (4 types), and
- shading (4 types)

the analysis tool provides data on the:

- energy consumption,
- present value and
- CO_2 saved

for 72 timber floor combinations of insulation, and 48 concrete floor combinations of insulation. This gave a total of 4,423,680 model runs (see Table 2), or 61,440 for each house in each location.

The user enters the period of years for the analysis, the discount rate and the energy escalation rate. The analysis tool calculates the present value of insulation costs plus discounted energy costs.

On the first screen (Figure 21) the user chooses an appropriate discount rate, which would normally be a “real rate”, i.e. a rate net of inflation. In that case energy escalation would normally be entered as zero. However if it was thought that energy prices might escalate above the rate of general inflation then the extra margin of escalation should be entered as the energy escalation rate. Note that different discount rates may be appropriate, depending on whether the perspective is from the homeowner’s viewpoint, or the society’s viewpoint. The homeowner’s opportunity cost of being forced to invest in insulation is the return they could obtain elsewhere. Hence an after-tax rate of return (excluding the rate of inflation) is the appropriate discount rate, rather than the higher mortgage interest rate that they pay. From society's perspective the discount rate may be even lower, to reflect externalities related to environmental impacts associated with energy savings.

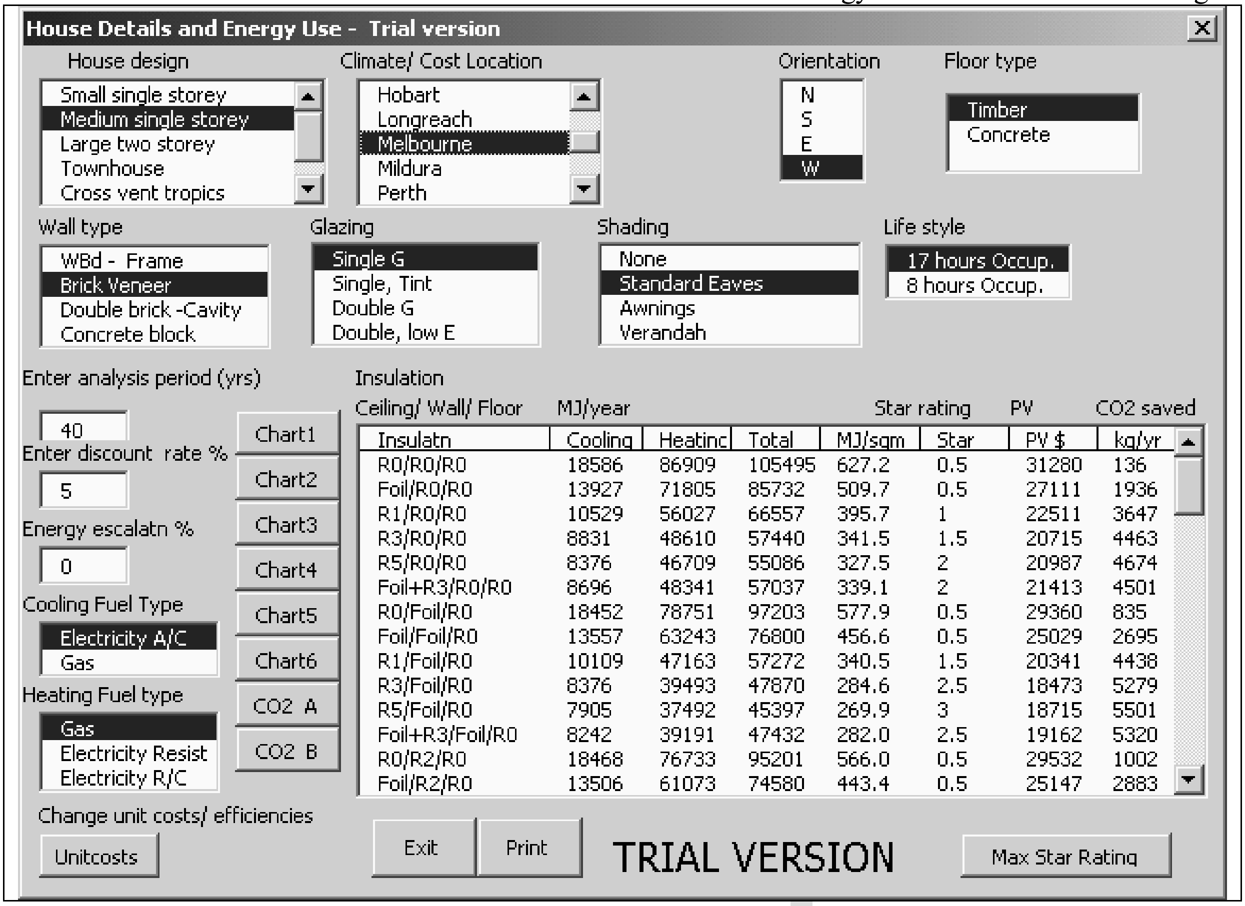


Figure 21: Financial Analysis Tool Data Entry - Screen 1

The user can chose either electricity or natural gas heating. For cooling, chose the electricity option unless a gas system is to be used. The analysis tool allows for different fuel efficiencies, but uses default options unless they are changed on the 'Unitcosts' screen. For electric cooling the default efficiency is 240%, and for heating the efficiencies are 100% for electricity and 61% for gas (See Section 3.8).

Unit costs were obtained from suppliers and are marginal costs, excluding fixed line costs. Where suppliers quote scaled tariffs depending on volume of use, the lowest unit cost has been used (see Section 3.6).

If no user selection is made, then the topmost choice in each of the selection windows is automatically made e.g. for 'House design' the default selection is 'Small single storey'. The results of the calculations are displayed in the large scrollable box in Screen 1. Star ratings are not provided for the reduced lifestyle ('8 hours Occup.'). In addition to providing an 'Exit' from the analysis tool, and the ability to send a 'Print' of the entry screen, Screen 1 also provides access to a second data management screen 'Unitcosts' and to a third screen for the calculation of 'Max Star Rating':

Unitcosts: This button goes to the second menu of the analysis tool (Figure 22), which permits the user to change the unit costs for energy, glazing and shading by entering a percentage change number in the second screen. The CO_2 intensity of electricity can also be changed on the second screen, as can the appliance efficiencies. Note all unit costs are exclusive of GST. In the example given in Figure 22, the cost of Double

Glazing has reduced by 20% compared to the base case, and Double Glazing with Low-E has reduced by 10%. The cost of Eaves have been reduced by 50% to account for the non-energy benefits provided by eaves. The replacement period for double glazing and awnings can also be changed, if desired.

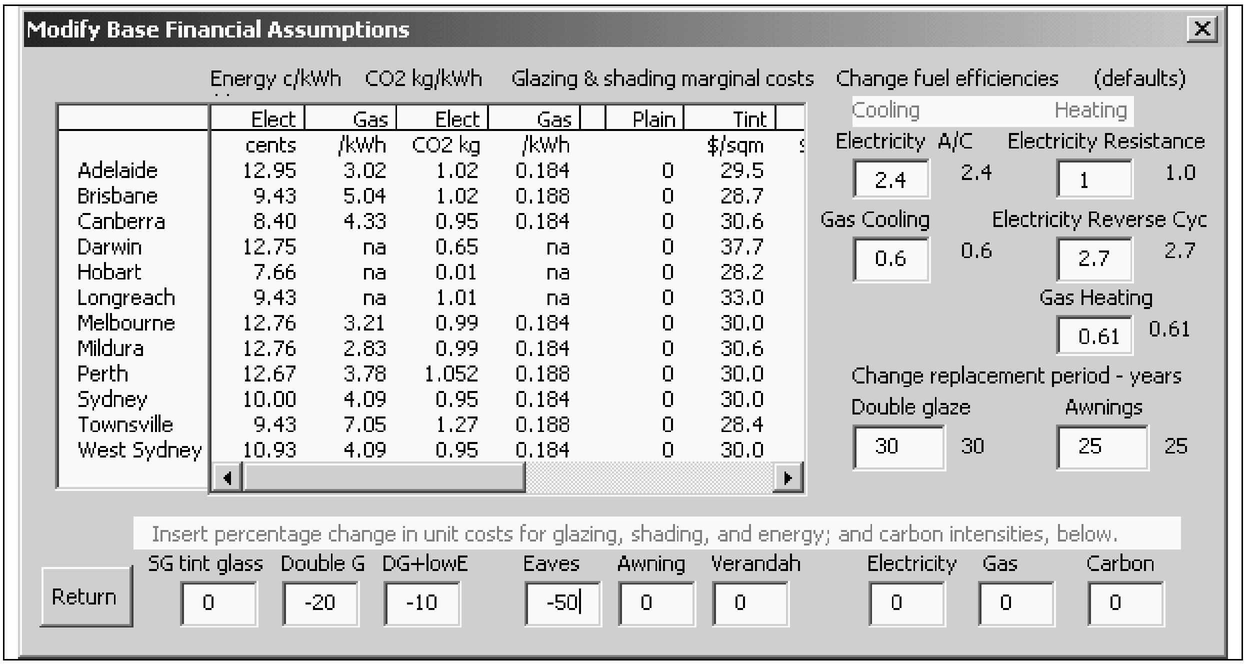


Figure 22: Financial Analysis Tool Data Entry – Screen 2

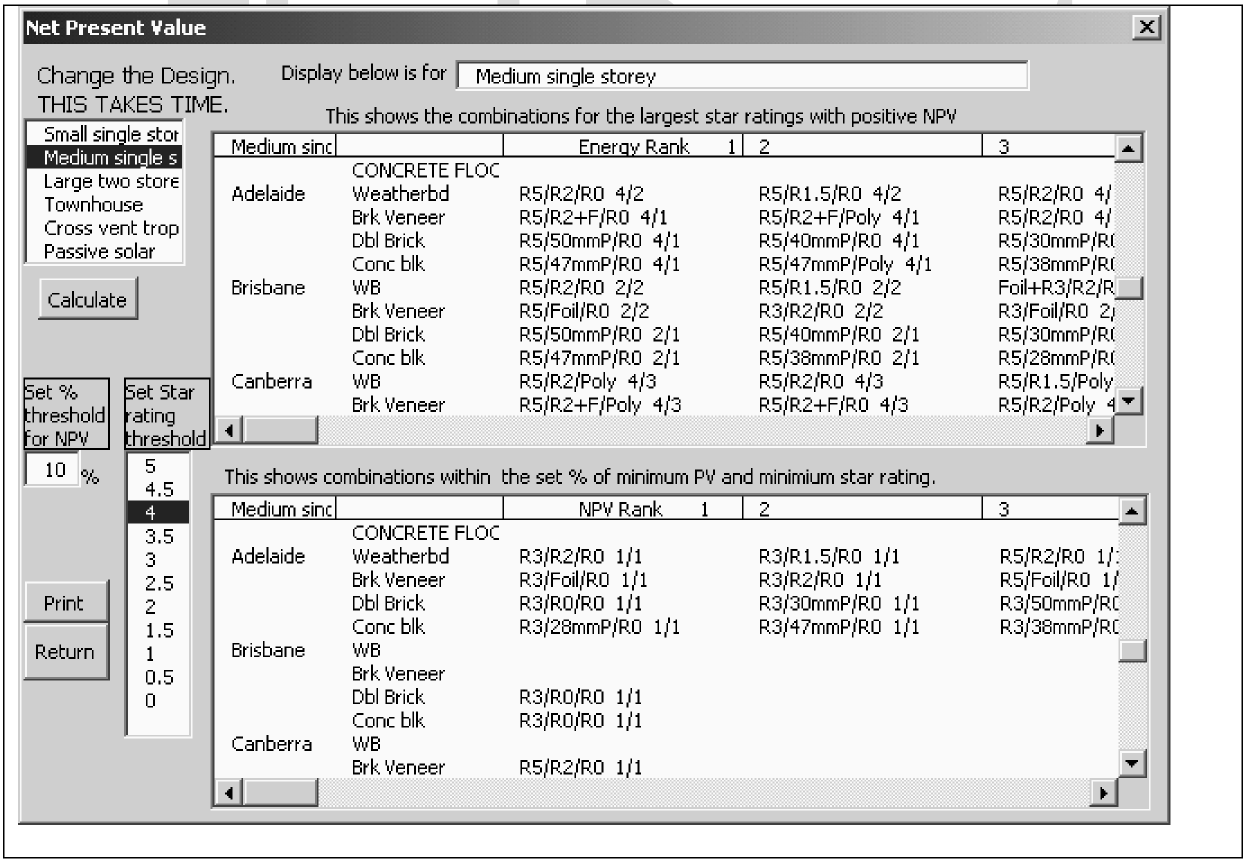


Figure 23: Financial Analysis Tool Data Entry - Screen 3

Max Star Rating: This button goes to a third screen (Figure 23) which permits the selection of the house type, the minimum Star Rating and the desired 'closeness' to the maximum NPV. The top scrollable table shows the 40 'best' energy rating insulation combinations with a positive NPV, for all locations for each wall and floor type. The lower scrollable panel shows the 40 'best' NPV insulation combinations for the Star rating set in the adjacent box. This needs to be re-calculated each time the assumptions or design are changed. Calculation commences with pressing the 'Calculate' button. This calculation takes some time, as all locations and wall types are processed in sequence. While the calculation is progressing, an indicator counter is displayed in the lower left hand corner of the screen. However changing only the NPV (%) and / or the Star (number of Stars) threshold(s) gives instantaneous results, as no new calculations are required.

A change to the Star rating threshold alters both panels, but changing the NPV threshold affects only the second panel. The displays are of all combinations within the thresholds chosen by the user for the minimum NatHERS Star Rating, and, in the case of the second panel, % variation from maximum NPV. A selection of 5 Stars rating will give only a few combinations in both panels. A selection of 99% NPV threshold and minimum of 0 Star rating will give the first 40 maximum NPV combinations, in rank order in the lower panel. A more common choice might be combinations within 5% of maximum NPV (i.e. between 95% and 100% of the maximum Net Present Value) and minimum of 4 Stars or over (i.e. rated between 4 and 5 NatHERS stars).

Eight charts are available from the financial tool. When each chart has been selected and is being viewed, a 'button box' provides the ability to 'Print' the chart, or 'Return' to Screen 1. Each chart is now described in turn.

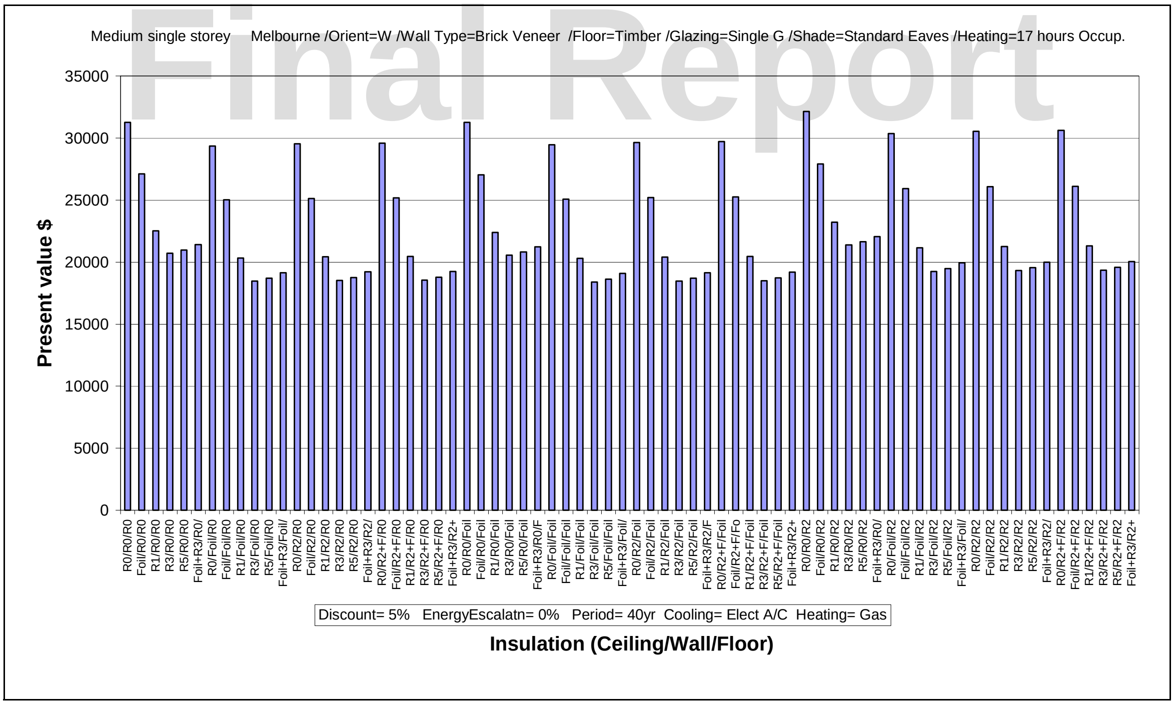


Figure 24: Example of Chart 1

Chart 1: Present Value for each combination of insulation (Figure 24). The Present Value is the insulation costs (capital cost) plus discounted energy costs (running costs). Figure 24 indicates quite wide variations in present value for the different combinations. Note however, that for most designs and locations there are a number of combinations close to the minimum present value combination.

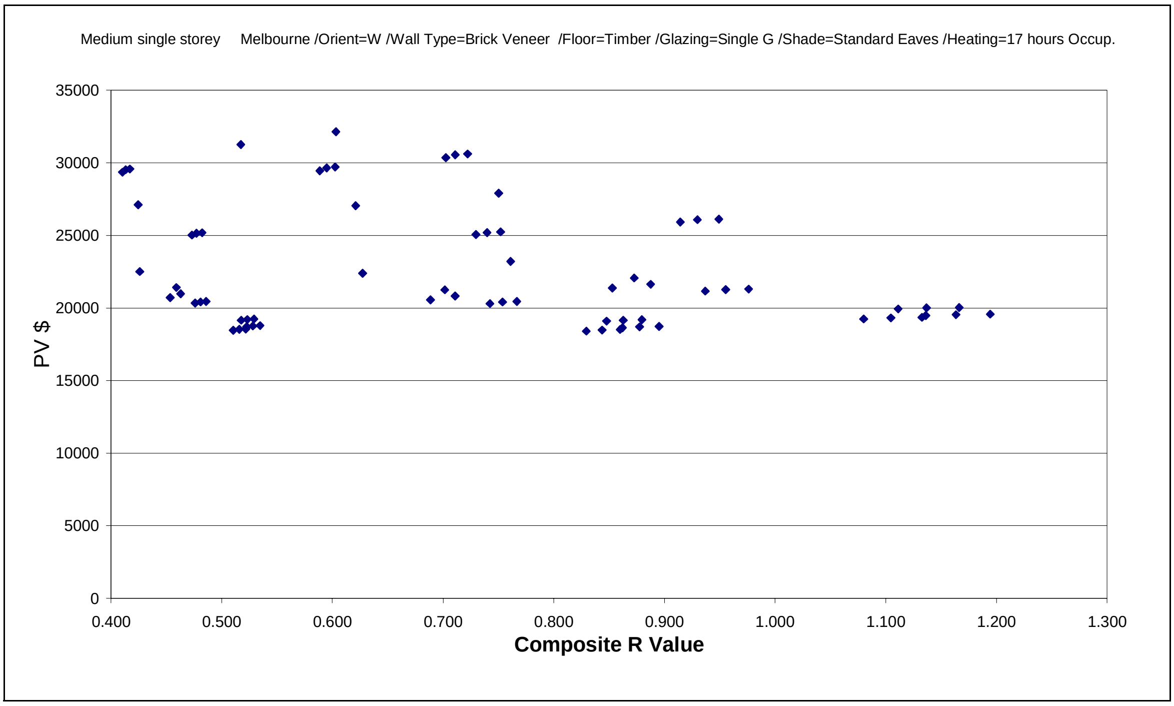


Figure 25: Example of Chart 2

Chart 2: Present Value plotted against the composite R-value for each insulation combination (Figure 25). The combined R-value is the appropriately weighted sum of R-value of each component (i.e. wall, ceiling, floor and glazing) following Equation 1 (page 33). Note that typically combinations close to the minimum present values are spread across the x axis, indicating the quite different amounts of insulation in different locations can have similar financial outcomes.

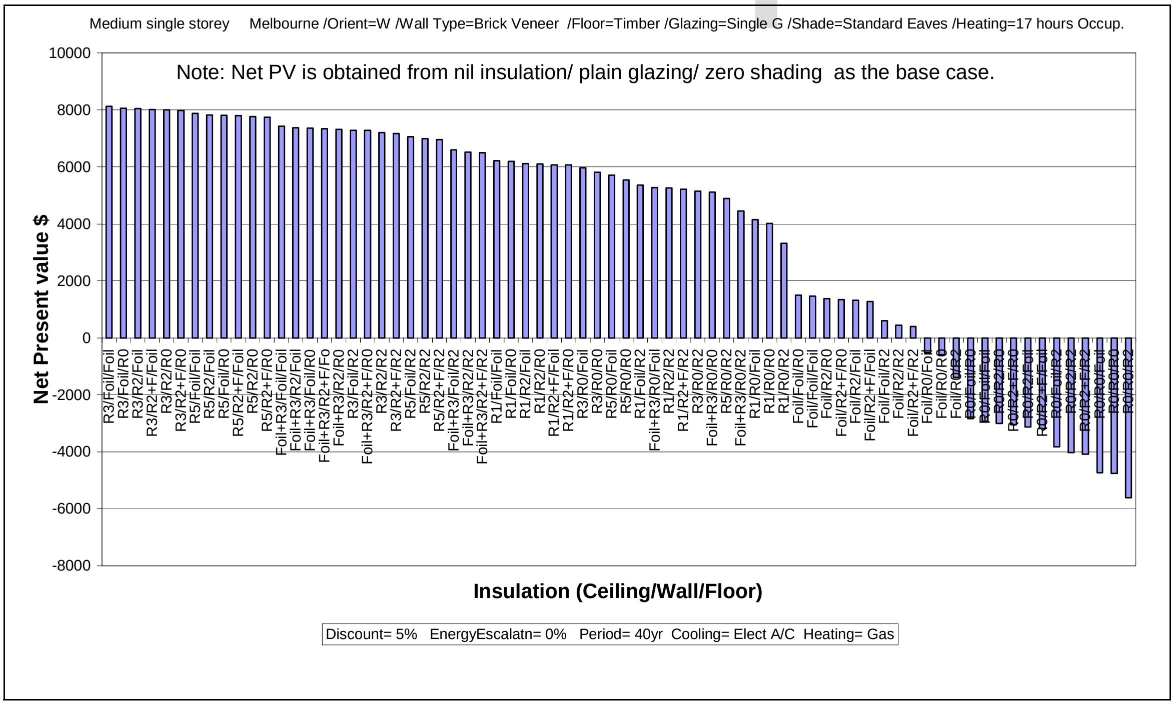


Figure 26: Example of Chart 3

Chart 3: Net Present Value (NPV) for each insulation combination (Figure 26). The base case is no insulation, single glazing, and no shading. The y-axis value is given by Equation 8

$$NPV_{(\text{insulation case k})} = PV_{(\text{base case})} - PV_{(\text{insulation case k})}.$$

Equation 8

Cases have been ranked in descending order, so that insulation combinations on the left have the highest Net Present Value. Note that some combinations have negative NPV, i.e. those combinations have net costs, or in other words, the value of discounted energy savings does not cover the cost of insulation.

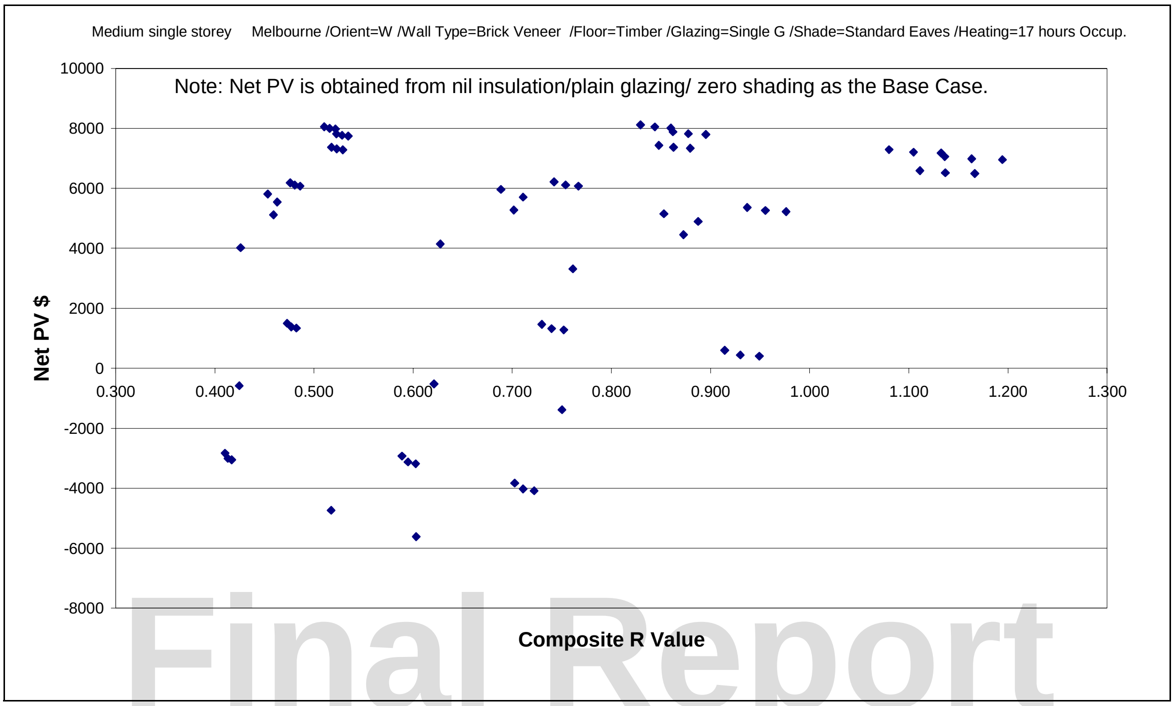


Figure 27: Example of Chart 4

Chart 4: Net Present Value, with the base case as per Chart 3, plotted against the combined R-value for each insulation combination (Figure 27).Chart 4 provides an intermediate step between Chart 3 (Figure 26) and Chart 5 (Figure 28). It illustrates how the NPV changes with the improved overall envelope thermal performance, but the cost of improving the energy performance of one component need not be the same as the cost of improving a different component. The result is that even though the composite R-value of the entire building improves, the cost benefit (NPV) may improve or worsen depending on the cost of improving that particular component (see also Section 4.4).

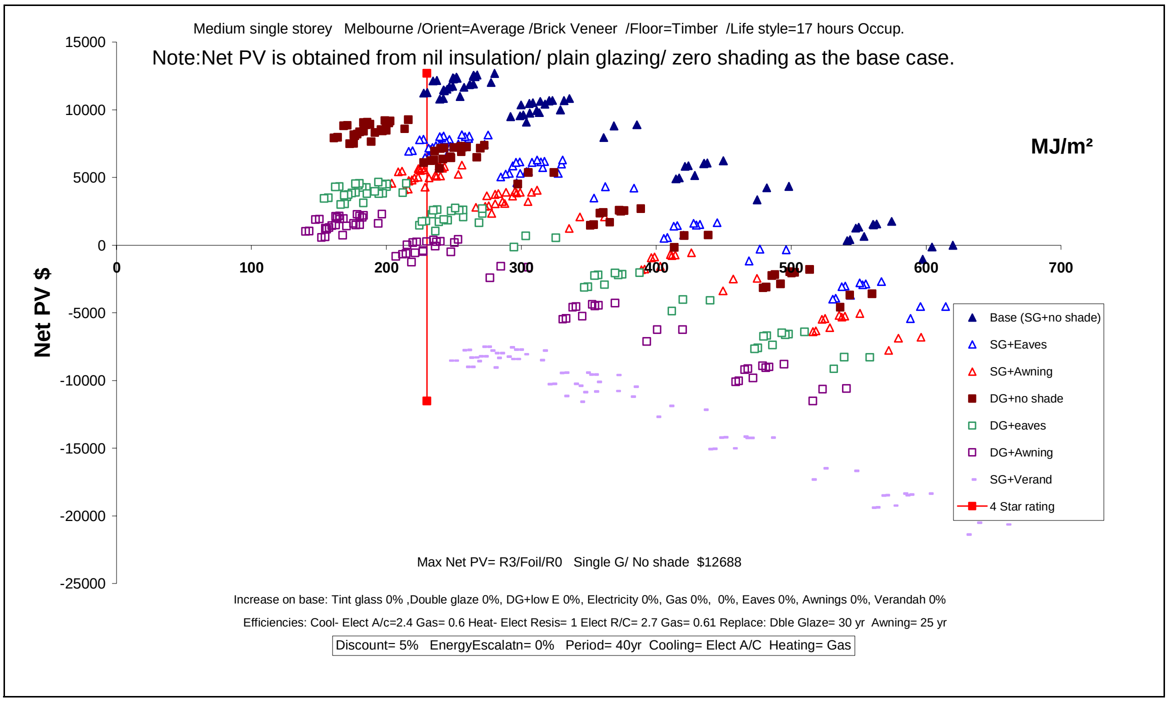


Figure 28: Example of Chart 5

Chart 5: The Net Present Value plotted against energy consumption per sq metre of floor area for each combination of insulation (Figure 28). The base case is the present value for energy use, averaged over the four orientations and with zero insulation, single glazing, and no shading. Calculations for the various insulation combinations are based on average energy use over the four orientations. Only seven sets of combinations of glazing and shading are shown in this chart, out of the 16 possible combinations (i.e. 4 glazing types by 4 shading types). The reason is to reduce the amount of data per chart.

The NatHERS 4 Star energy use is shown as a vertical line, and points to the left are energy efficiency combinations that result in the house energy use equal or exceed four Stars. Note that the NatHERS 4 Star line will change depending upon the location.

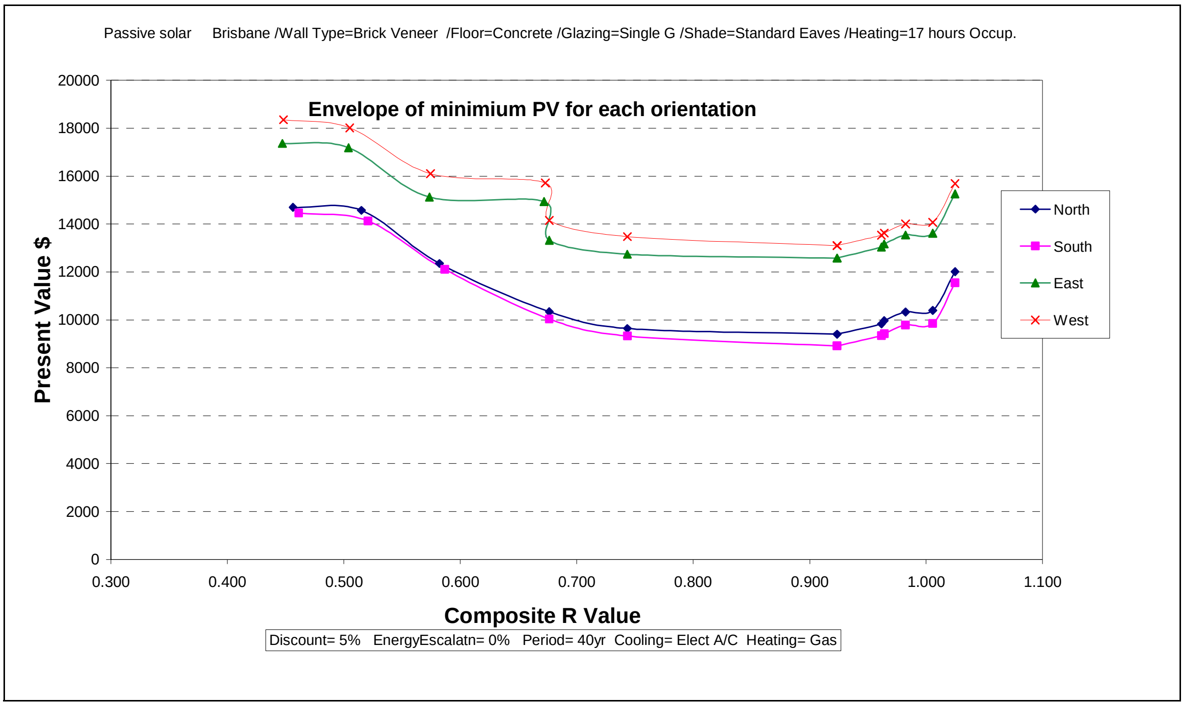


Figure 29: Example of Chart 6

Chart 6: The lower envelope of Present Values from Chart 1 are shown for all four orientations in Figure 29. Figure 29, unlike the other example charts in this section, is for the 'Passive solar design' located in Brisbane. The importance of directionality for this house is shown by the spread of the PV for the different orientations. As the BCA does not specify orientation, and the orientation selected as 'North' cannot be guaranteed to be the case for any of the designs selected, an average of all four orientations is used in the following analysis. In general, for the first three house designs in all locations this chart has the PV lines for each orientation close together. The other three designs tend to have a wider spread, as expected given the glazing directionality (see Table 5). The minimum PV insulation combination is usually the same for each orientation.

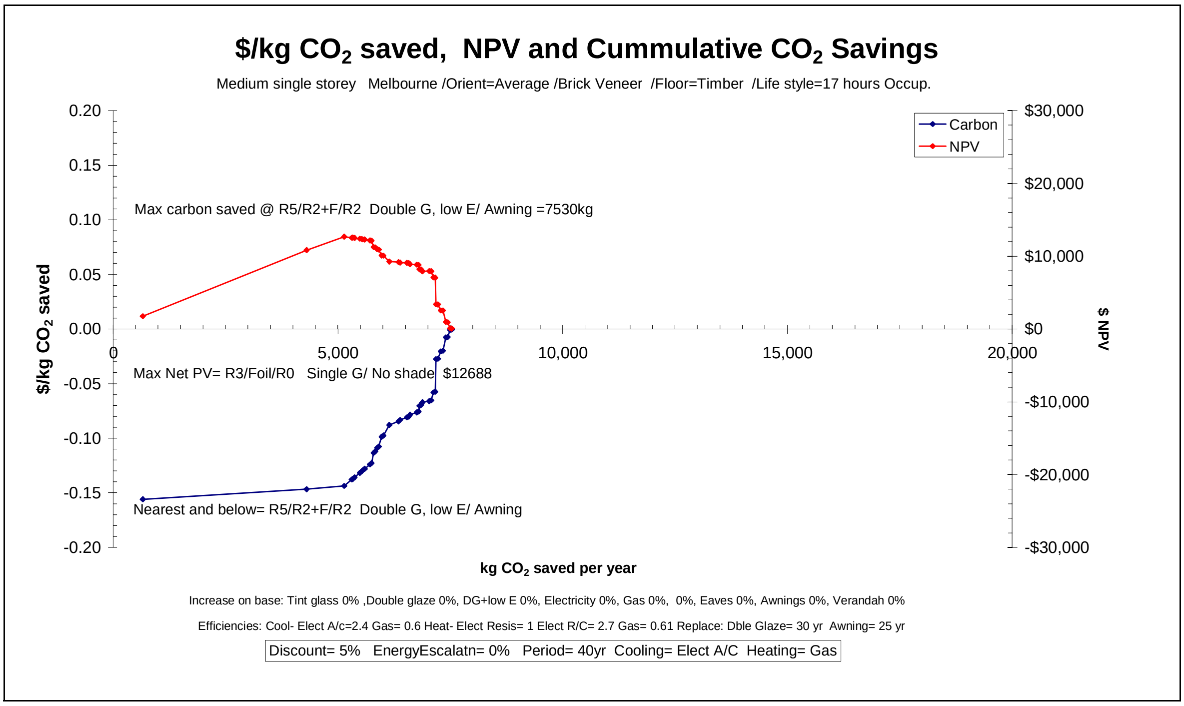


Figure 30: Example of Chart CO_2 A

The final two graphs provide an overview of the cost of CO_2 savings compared to the NPV, total CO_2 saved and total energy saved per year.

CO_2 A: (Figure 30) – CO_2 savings supply curve: Two lines are shown on this chart. The lower line is the $ per kg of CO_2 saved for "outer envelope" combinations of insulation. This is the so called "CO_2 supply" line. The $ amount is the Net Present Value, with the base case as per Chart 5. The calculation of CO_2 savings is the average of four orientations with nil insulation, single glazing, and no shade as the base case. The CO_2 saved line is below the x-axis for each insulation combination that has a positive NPV. Above the x-axis cost of the insulation exceeds the discounted value of the energy savings and there is a net cost to save additional CO_2.

CO_2 B: (Figure 31**)** – Energy savings supply curve: This shows the CO_2 supply line from the previous chart, with the same insulation combinations and same vertical axis. But the x axis is energy use, rather than CO_2 saved. The line may "fold-in" on itself in those locations where significant amounts of different fuel types are used for heating and cooling, e.g. Adelaide, Melbourne or Sydney. Points below the x-axis and to the left of the four Star Rate line are combinations with positive NPV and very good energy performance. They can each be identified on the print out. Note that in some cases there are no combinations of energy efficiency alternatives for a given house construction with both a positive NPV and a 4 Star (or better) NatHERS rating.

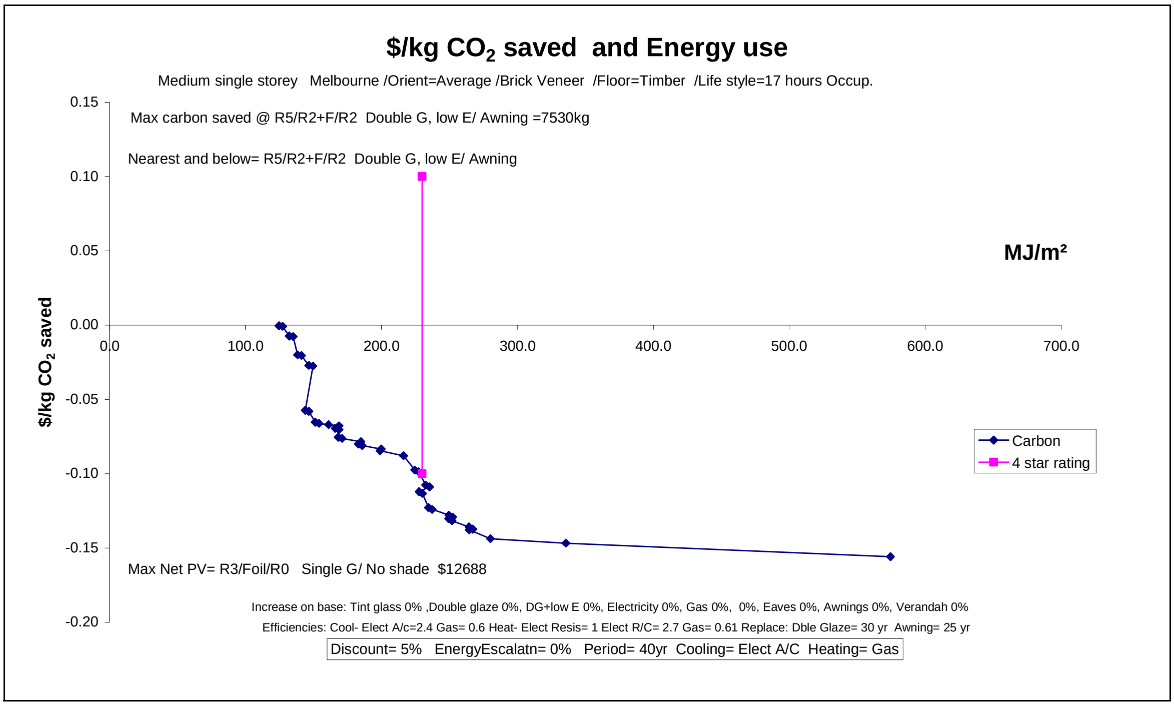


Figure 31: Example of Chart CO_2 B

The 'print' output for either of the CO_2 charts gives details of all points on the CO_2 and NPV line, as illustrated in Table 32 for the 'Medium single storey' house located in Melbourne with Brick Veneer walls, timber floor and the standard NatHERS occupancy schedule. the printout also gives a summary of the key assumptions (lifetime, energy types) and any modifications to the base costings.

Table 32 provides the cost for the CO_2 savings (negative values indicate a cost benefit from the saving, positive values a costs to the user), the amount of CO_2 saved per year, the energy efficiency combination that achieves this (formatted as Roof / Wall / Floor insulation Window / Shading alternative), the Net Present Value of that combination, the capital investment required, and the energy use per square metre per year. It also provides information on the cost of the energy efficiency combination as a percent of the total cost of the house, and the proportion of the maximum CO_2 savings for that option compared to the CO_2 savings for the energy efficiency combination having closest to zero NPV.

In this case the combination closest to zero NPV has R-5 insulation in the ceiling, R 2 plus foil in the walls, R 2 under floor insulation, low-e double glazed windows with awnings over all windows. This package of energy efficiency options costs 8% of the total cost of the house. The case with Maximum NPV has R 3 in the roof, foil in the walls and no insulation under the floor, single glazing and no shading. This package costs 0.8% of the total cost of the house, and saves 68% of the maximum CO2 savings.

$/kg CO_{2saved}	CO_{2saved} kg/yr	Insulation Glaze/Shade	NPV $	Capital $	Energy MJ/m²	% Capital	% CO_2 savings
-0.1559	657	R0/Foil/R0 1/1	1758	159	574.5	0.1	8.7
-0.1468	4304	R1/Foil/R0 1/1	10839	1176	335.7	0.5	57.1
-0.1438	5143	R3/Foil/R0 1/1	12688	1671	280.2	0.8	68.3
-0.1378	5308	R3/Foil/Foil 1/1	12552	2459	264.7	1.1	70.4
-0.1374	5330	R3/R2/R0 1/1	12563	2345	267.2	1.1	70.7
-0.1359	5371	R3/R2+F/R0 1/1	12522	2504	264.4	1.1	71.3
-0.1317	5491	R3/R2/Foil 1/1	12412	3133	252.0	1.4	72.9
-0.1303	5530	R3/R2+F/Foil 1/1	12367	3292	249.3	1.5	73.4
-0.1293	5555	R5/R2/R0 1/1	12327	3209	252.4	1.5	73.7
-0.1280	5595	R5/R2+F/R0 1/1	12285	3368	249.6	1.5	74.3
-0.1241	5712	R5/R2/Foil 1/1	12168	3996	237.4	1.8	75.8
-0.1228	5752	R5/R2+F/Foil 1/1	12124	4155	234.7	1.9	76.3
-0.1134	5795	R5/R2/R2 1/1	11273	5190	230.3	2.4	76.9
-0.1121	5832	R5/R2+F/R2 1/1	11223	5349	227.7	2.4	77.4
-0.1089	5871	R5/R2/Foil 2/1	10970	5286	235.5	2.4	77.9
-0.1077	5912	R5/R2+F/Foil 2/1	10930	5445	232.7	2.5	78.5
-0.0987	5975	R5/R2/R2 2/1	10118	6480	227.4	2.9	79.3
-0.0976	6014	R5/R2+F/R2 2/1	10074	6639	224.6	3.0	79.8
-0.0879	6144	R3/Foil/R0 3/1	9267	6646	216.3	3.0	81.5
-0.0846	6345	R3/Foil/Foil 3/1	9208	7434	198.9	3.4	84.2
-0.0834	6382	R3/R2+F/R0 3/1	9129	7479	199.9	3.4	84.7
-0.0810	6535	R3/R2/Foil 3/1	9088	8108	185.8	3.7	86.7
-0.0802	6574	R3/R2+F/Foil 3/1	9044	8267	183.1	3.7	87.3
-0.0785	6606	R5/R2+F/R0 3/1	8893	8343	185.0	3.8	87.7
-0.0763	6757	R5/R2/Foil 3/1	8848	8972	171.1	4.1	89.7
-0.0755	6796	R5/R2+F/Foil 3/1	8805	9131	168	4.1	90.2
-0.0703	6814	R3/R2/Foil 4/1	8220	9398	169	4.3	90.4
-0.0695	6854	R3/R2+F/Foil 4/1	8179	9557	166	4.3	91.0
-0.0678	6868	R5/R2+F/R0 4/1	7990	9633	169	4.4	91.2
-0.0670	6882	R5/R2+F/R2 3/1	7912	10324	161	4.7	91.3
-0.0661	7035	R5/R2/Foil 4/1	7978	10262	154	4.7	93.4
-0.0654	7075	R5/R2+F/Foil 4/1	7938	10421	151	4.7	93.9
-0.0580	7126	R5/R2/R2 4/1	7097	11455	147	5.2	94.6
-0.0574	7164	R5/R2+F/R2 4/1	7052	11614	144	5.3	95.1
-0.0276	7184	R5/R2/Foil 4/2	3398	15038	150	6.8	95.3
-0.0271	7227	R5/R2+F/Foil 4/2	3365	15197	147	6.9	95.9
-0.0204	7292	R5/R2/R2 4/2	2559	16231	141	7.4	96.8
-0.0200	7333	R5/R2+F/R2 4/2	2522	16390	138	7.4	97.3
-0.0077	7400	R5/R2/Foil 4/3	980	16288	135	7.4	98.2
-0.0074	7441	R5/R2+F/Foil 4/3	940	16447	132	7.5	98.8
-0.0008	7496	R5/R2/R2 4/3	109	17482	127	7.9	99.5
-0.0005	7535	R5/R2+F/R2 4/3	65	17641	125	8.0	100.0

Table 32: Example of $C0_2$ Results

Notes to Table 32: (4 star rating in Melbourne = 230.0 MJ/m²)

- Based on: Medium single storey house, located in Melbourne with average orientation, Brick Veneer walls, timber suspended floor, 17 hours Occupancy.
- Efficiencies: Cooling- Electric air conditioning =240% Heat- Gas= 61%
- Replacements: Double Glazing after 30 years and Awning after 25 years

5.6 Selected Financial Analysis Tool Outputs

Figure 32 is a typical example of Chart 3. In all the charts, a summary of the house parameters is provided in the title, and the insulation coding is Ceiling/ Walls/ Floor (e.g. 'Foil/Foil/0' is the case with foil insulation in the ceiling, foil insulation in the walls and no insulation under the floor). Figure 32 shows the Net Present Value for the medium size, single storey house with the zero insulation, plain glazing, and no shade, as the base case. The highest NPV insulation package in this case is R3 ceilings, foil in the wall, and nil in the floor. Insulation combinations down to R0/ Foil/ Foil have a positive NPV.

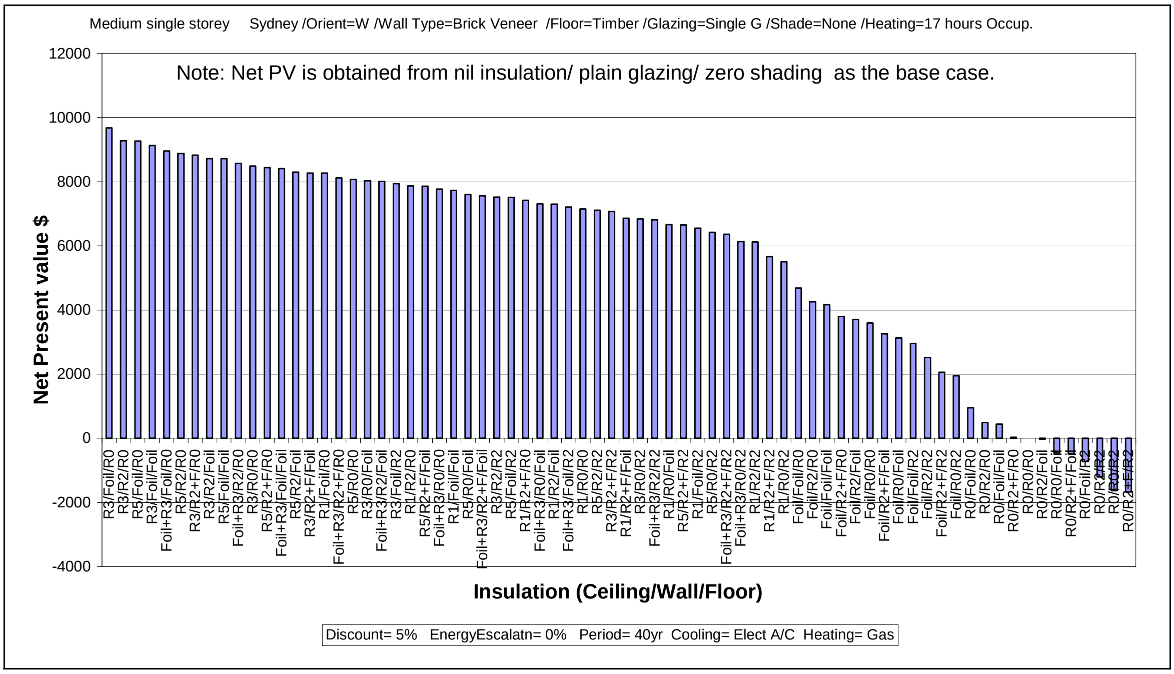


Figure 32: Net Present Value chart

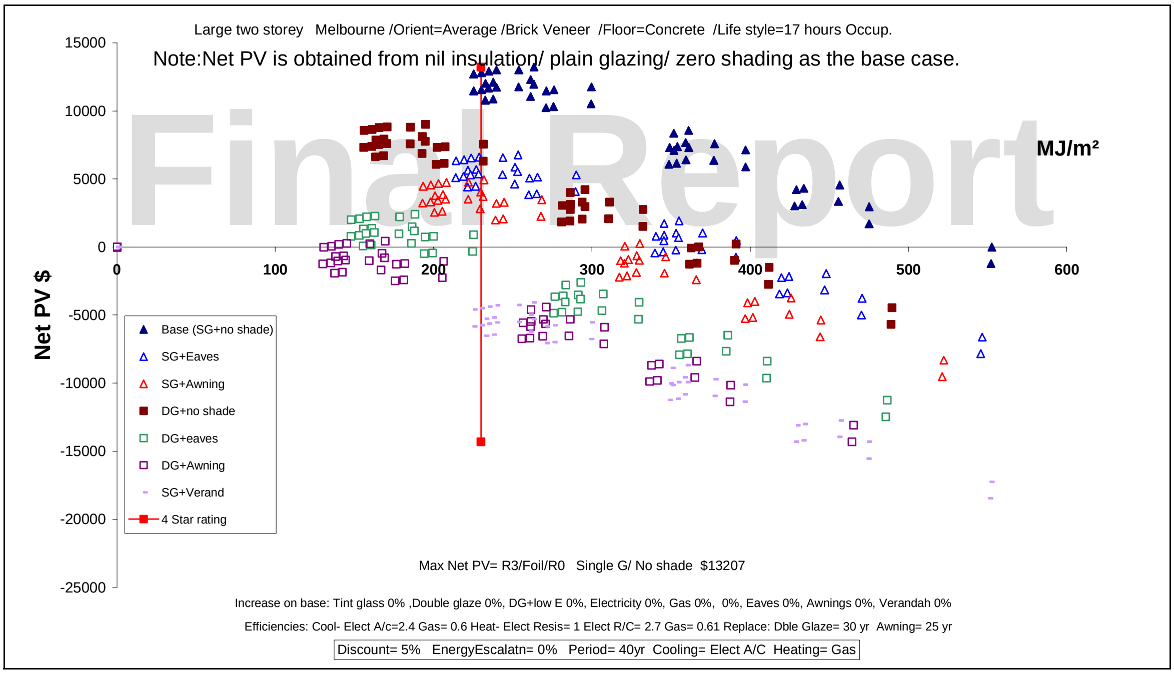


Figure 33: NPV vs. Energy Consumption

Figure 33 is a typical example of Chart 5. It shows NPV for all the insulation combinations and seven sets of combination of glazing and shade. The calculations are based on the average energy use over all four orientations. In Figure 33 the highest NPV combinations are with plain glazing and no shade. Some of the double-glazing combinations have lower energy use, and their NPV is positive, but the NPV is less than plain glazing /no shading combinations. There are a significant number of combinations with ratings over 4 Stars and with positive NPV, to the left of the 4-star line and above the horizontal axis. The specific combinations can be identified from the 'Max Star Rating' printout table (see Table 32 as an example). Decreasing the analysis period, for example reducing it from 40 years to 25 years 'raises' the x-axis resulting in a larger number of combinations not achieving a positive NPV.

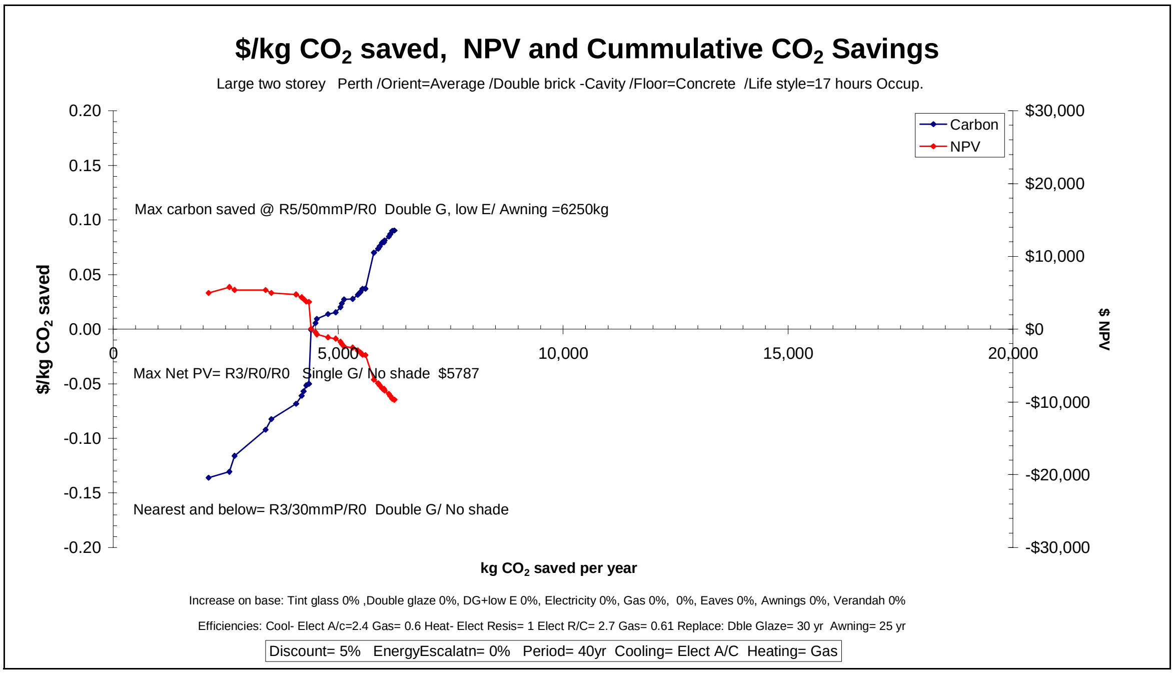


Figure 34: Example of CO_2 'Supply Curve'

Figure 34 (Chart CO_2 A)is a typical CO_2 "supply curve", in this case for a large two storey, cavity brick wall, Perth house. It shows the unit cost to achieve CO_2 savings, at various amounts of saving, and is analogous to the traditional supply curve in microeconomic theory. Most of the supply curve is below the x-axis, since all the energy efficiency combinations below the axis have a positive NPV. Figure 34 shows that in this case R3 (ceiling) / R0 (wall) / R0 (floor), single glass with no shading, is the combination with the maximum NPV. However, Figure 34 also shows that more insulation, up to R3/ 30 mm polystyrene /R0, double glazing and no shading, has a positive NPV and is the point just below the axis, saving about 4,500 kg CO_2 per year. To save more CO_2 has a net cost, and the maximum amount saved for these energy efficiency alternatives is 6,250 kg CO_2 per year, with the combination R5/ R2/ R0, DG low-E, awning, at a net cost of about 9 cents per kg CO_2 saved.

Figure 34 also shows the net present value for the same insulation combinations in the CO_2 curve. The base case for the comparison NPV and CO_2 saved is no insulation, plain glazing, and no shading.

Figure 35 (Chart CO_2 B) illustrates that there is only one 4 Star insulation combination that has positive NPV (i.e. the point is below the x axis and to the left of the 4 star line) and also lies on the supply curve. This combination can be identified from the printout. There may be other combinations that satisfy this condition but lie inside the supply envelope, and they are best identified from the 'Max Star Rating' screen or printout.

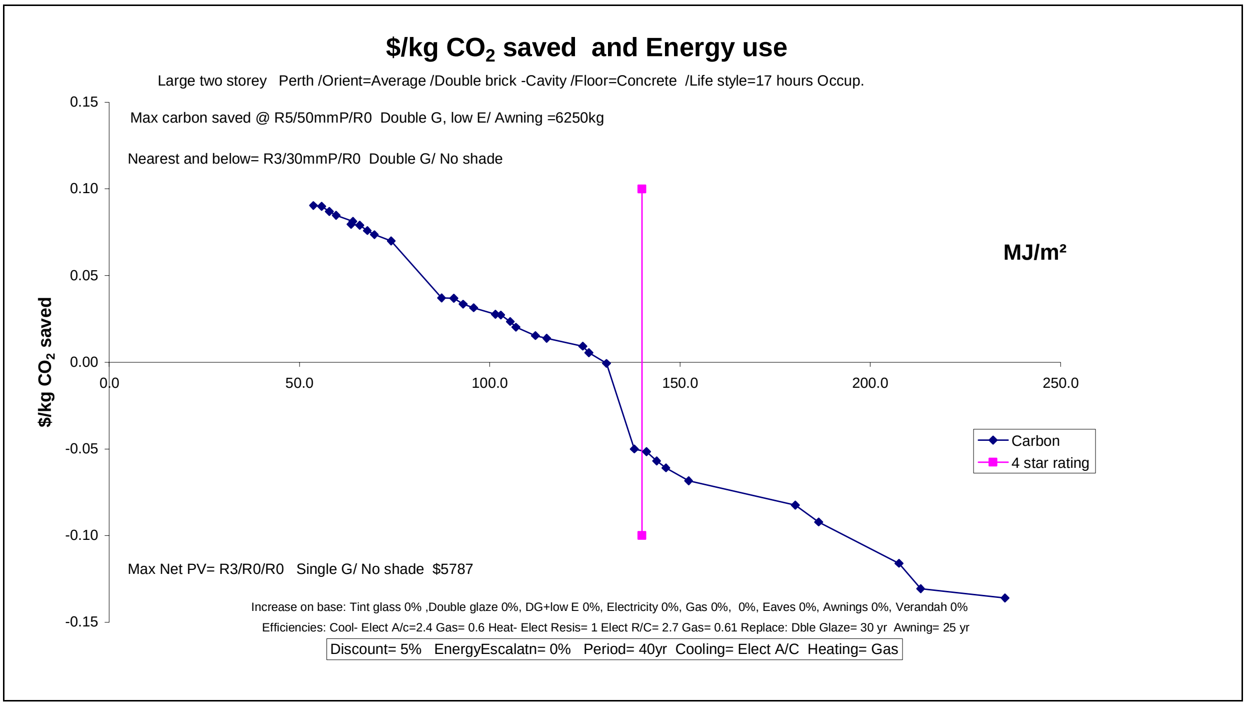


Figure 35: CO_2 and Energy Savings

5.7 Combinations For Maximum Star Rating Or NPV

For most designs and locations there are a large number of insulation combinations, which have 4 Stars or better rating and still have a positive NPV. However there are likely to be fewer combinations, if any, that are close to the maximum NPV and still have a high Star rating. The analysis tool enables these combinations to be determined. Note that in locations with no gas, namely Darwin, Hobart and Longreach, if "Gas" is selected for heating, then the tool defaults to "Electric Resistance" for the analysis. The "Electric Reverse Cycle" heating option must be explicitly selected if it is to be used.

Table 33 shows insulation combinations for the medium single storey house that have the best energy rating over 4 Stars and still have a positive Net Present Value. This table is generated by sorting by energy rating, with positive NPV being the only other criteria. Hence up to 40 combinations are found by the analysis tool. In some cases there are no, or very few combinations.

Table 34 shows the first 5 insulation combinations, for the medium single storey house with concrete floor for all wall types, any Star rating, that have the highest NPV. It is possible, depending on the financial assumptions, in some locations there will be no other combination within 5% of the maximum value.

Location	Wall	1	2	3	4	5
Adelaide	Weatherbd	R5/R2/R0 4/3	R5/R1.5/R0 4/3	Foil+R3/R2/R0 4/3	R5/R2/R0 3/3	R3/R2/R0 4/3
	Brk Veneer	R5/R2/R0 3/3	R5/R2+F/R0 4/2	R5/R2/R0 4/2	R5/R2/Poly 4/2	R5/R2+F/R0 4/1
	Dbl Brick	R5/50mmP/R0 4/1	R5/50mmP/Poly 4/1	R5/50mmP/R0 4/2	R5/40mmP/R0 4/1	R5/40mmP/Poly 4/1
	Conc blk	R5/47mmP/R0 4/1	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/2	R5/38mmP/R0 4/1	R5/38mmP/Poly 4/1
Brisbane	WB	R5/R2/R0 2/2	R5/R2/Poly 2/2	R5/R1.5/R0 2/2	R5/R1.5/Poly 2/2	Foil+R3/R2/R0 2/2
	Brk Veneer	R5/R2+F/R0 2/2	R5/R2/R0 2/2	R5/Foil/R0 2/2	R5/Foil/Poly 2/2	Foil+R3/R2+F/R0 2/2
	Dbl Brick	R5/50mmP/R0 2/1	R5/40mmP/R0 2/1	R5/50mmP/Poly 2/1	R3/50mmP/R0 1/2	R5/40mmP/Poly 2/1
	Conc blk	R5/47mmP/R0 2/1	R5/38mmP/R0 2/1	R5/28mmP/R0 2/1	Foil+R3/47mmP/R0 2/1	R3/47mmP/R0 2/1
Canberra	WB	R5/R2/Poly 4/3	R5/R2/R0 4/3	R5/R1.5/Poly 4/3	R5/R1.5/R0 4/3	R5/R2/Poly 3/3
	Brk Veneer	R5/R2+F/Poly 4/3	R5/R2+F/R0 4/3	R5/R2/Poly 4/3	R5/R2/R0 4/3	Foil+R3/R2+F/Poly 4/3
	Dbl Brick	R5/50mmP/Poly 4/3	R5/50mmP/R0 4/3	R5/40mmP/Poly 4/3	R5/40mmP/R0 4/3	R5/50mmP/Poly 4/1
	Conc blk	R5/47mmP/Poly 4/3	R5/47mmP/R0 4/3	R5/38mmP/Poly 4/3	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/1
Darwin	WB	R5/R2/R0 4/3	R5/R1.5/R0 4/3	Foil+R3/R2/R0 4/3	R3/R2/R0 4/3	Foil+R3/R1.5/R0 4/3
	Brk Veneer	R5/R2+F/R0 4/3	R5/R2/R0 4/3	Foil+R3/R2+F/R0 4/3	Foil+R3/R2/R0 4/3	R3/R2+F/R0 4/3
	Dbl Brick	R5/50mmP/R0 2/3	R3/50mmP/R0 3/3	R5/40mmP/R0 2/3	R5/50mmP/Poly 2/3	R3/40mmP/R0 3/3
	Conc blk	R5/47mmP/R0 3/3	R5/38mmP/R0 3/3	Foil+R3/47mmP/R0 3/3	R5/47mmP/R0 2/3	R5/28mmP/R0 3/3
Hobart	WB	R5/R2/Poly 4/3	R5/R2/Poly 4/1	R5/R2/R0 4/3	R5/R2/R0 4/1	R5/R1.5/Poly 4/3
	Brk Veneer	R5/R2+F/Poly 4/3	R5/R2+F/Poly 4/1	R5/R2+F/R0 4/3	R5/R2/Poly 4/3	R5/R2+F/R0 4/1
	Dbl Brick	R5/50mmP/Poly 4/3	R5/50mmP/Poly 4/1	R5/50mmP/R0 4/3	R5/50mmP/R0 4/1	R5/40mmP/Poly 4/3
	Conc blk	R5/47mmP/Poly 4/3	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/3	R5/47mmP/R0 4/1	R5/38mmP/Poly 4/3
Longreach	WB	R5/R2/R0 2/3	R5/R2/Poly 2/3	R5/R2/R0 4/2	R5/R1.5/R0 2/3	R5/R1.5/Poly 2/3
	Brk Veneer	R5/R2+F/R0 2/3	R5/R2/R0 2/3	Foil+R3/R2+F/R0 2/3	R5/Foil/R0 2/3	Foil+R3/R2/R0 2/3
	Dbl Brick	R5/50mmP/R0 2/2	R5/40mmP/R0 2/2	R5/30mmP/R0 2/2	R5/30mmP/Poly 2/2	Foil+R3/50mmP/R0 2/2
	Conc blk	R5/47mmP/R0 2/2	R5/38mmP/R0 2/2	R5/28mmP/R0 2/2	Foil+R3/47mmP/R0 2/2	Foil+R3/38mmP/R0 2/2
Melbourne	WB	R5/R2/R0 4/3	R5/R1.5/R0 4/3	R5/R2/R0 3/3	R3/R2/R0 4/3	R5/R2/Poly 4/2
	Brk Veneer	R5/R2+F/R0 3/3	R5/R2/R0 3/3	R5/R2+F/Poly 4/1	R5/R2+F/R0 4/1	R5/R2+F/Poly 4/2
	Dbl Brick	R5/50mmP/Poly 4/1	R5/50mmP/R0 4/1	R5/40mmP/Poly 4/1	R5/40mmP/R0 4/1	R5/50mmP/Poly 4/2
	Conc blk	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/1	R5/38mmP/Poly 4/1	R5/38mmP/R0 4/1	R5/47mmP/Poly 4/2
Mildura	WB	R5/R2/R0 4/3	R5/R1.5/R0 4/3	R5/R2/R0 3/3	R3/R2/R0 4/3	R5/R1.5/R0 3/3
	Brk Veneer	R5/R2+F/R0 3/3	R5/R2/R0 3/3	R5/R2+F/R0 4/2	R5/R2+F/Poly 4/2	R5/R2/R0 4/2
	Dbl Brick	R5/50mmP/R0 4/1	R5/50mmP/Poly 4/1	R5/50mmP/R0 4/2	R5/40mmP/R0 4/1	R5/40mmP/Poly 4/1
	Conc blk	R5/47mmP/R0 4/1	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/2	R5/38mmP/R0 4/1	R5/38mmP/Poly 4/1
Perth	WB	R5/R2/R0 4/2	R5/R1.5/R0 4/2	Foil+R3/R2/R0 4/2	R3/R2/R0 4/2	Foil+R3/R1.5/R0 4/2
	Brk Veneer	R5/R2/R0 4/2	R5/Foil/R0 4/2	R3/R2+F/R0 4/2	R3/R2/R0 4/2	R5/R2+F/R0 3/2
	Dbl Brick	R5/50mmP/R0 4/1	R5/40mmP/R0 4/1	R5/30mmP/R0 4/1	Foil+R3/50mmP/R0 4/1	Foil+R3/40mmP/R0 4/1
	Conc blk	R5/47mmP/R0 4/1	R5/38mmP/R0 4/1	R5/47mmP/R0 1/3	R5/38mmP/R0 1/3	Foil+R3/47mmP/R0 4/1
Sydney	WB	R5/R2/R0 3/2	R5/R2/R0 4/1	R5/R1.5/R0 3/2	R5/R2/Poly 4/1	R5/R1.5/R0 4/1
	Brk Veneer	R5/R2+F/R0 4/1	R5/R2+F/Poly 4/1	R5/R2/R0 4/1	R5/R2/Poly 4/1	Foil+R3/R2+F/R0 4/1
	Dbl Brick	R5/50mmP/R0 4/1	R5/40mmP/R0 4/1	R5/30mmP/R0 4/1	R5/30mmP/Poly 4/1	Foil+R3/50mmP/R0 4/1
	Conc blk	R5/47mmP/R0 4/1	R5/38mmP/R0 4/1	Foil+R3/47mmP/R0 4/1	R5/28mmP/R0 4/1	R5/28mmP/Poly 4/1
Townsville	WB					
	Brk Veneer					
	Dbl Brick					
	Conc blk					
West Sydney	WB	R5/R2/R0 4/3	R5/R1.5/R0 4/3	R5/R2/Poly 4/2	R5/R2/R0 4/2	Foil+R3/R2/R0 4/3
	Brk Veneer	R5/R2+F/R0 4/2	R5/R2/R0 3/3	R5/R2/Poly 4/2	R5/R2/R0 4/2	R5/R2+F/R0 4/1
	Dbl Brick	R5/50mmP/Poly 4/1	R5/50mmP/R0 4/1	R5/40mmP/Poly 4/1	R5/40mmP/R0 4/1	R5/30mmP/Poly 4/1
	Conc blk	R5/47mmP/Poly 4/1	R5/47mmP/R0 4/1	R5/38mmP/Poly 4/1	R5/38mmP/R0 4/1	R5/47mmP/Poly 3/1
Assumptions: 5% discount rate, 40 years period, Cooling = Electricity A/C, Heating =Gas, Concrete Floor						

Table 33: Medium Single Storey: Combinations with 4 Stars or better, and Positive NPV.

NOTE to Table 33 & Table 34:
These tables are for insulation combinations with positive NPV only
When gas heating is the option, note that Darwin, Hobart and Longreach use electric resistance heating.

The "most appropriate" insulation combinations can be different depending on if the selection is based on Star rating or maximum NPV.

When energy efficiency, or Star rating, is the criteria, then the best insulation arrangements with positive NPV, are determined from Table 33 for brick veneer and concrete floors (where the coding is Ceiling/ Wall/ Floor, Glazing/ Shade):

- R5/ R2+Foil/ R0, Tint glazing or Double glazing/ Eaves or Awnings – Brisbane, Darwin, Longreach, Melbourne, Mildura, Sydney and West Sydney.
- R5/ R2+Foil/ Polystyrene, Double glazing-low E/ Awnings – Canberra, Hobart.
- R5/ R2/ R0, Double glazing/ Eaves or Awnings – Adelaide and Perth.

In Townsville there are no combinations that have 4 Stars. The main reason is the very low energy use per square meter bench mark for 4 Stars in Townsville, compared to other hot locations. It should be noted that this study has not investigated the appropriateness, or any other issues, of the Star Ratings for each location.

When Maximum NPV is the sole criteria (i.e. the Star rating is not considered), Table 34 reveals the insulation arrangements for brick veneer clad houses are:

- R3/ Foil/ R0 Plain glazing/Nil – Adelaide, Brisbane, Melbourne, Mildura, Perth, Sydney and West Sydney.
- R3/ Foil/ R0 Tint glazing/Nil – Darwin, Longreach, and Townsville.
- R5/ R2/ R0 Plain glazing/ Nil – Canberra, Hobart.

Table 33 and Table 34 provide alternatives only for the medium sized single storey house with a concrete floor. Comprehensive analyses for other designs have not been carried out, but a quick examination suggest these insulation combinations would be similar for the other house designs.

Location	Wall	1	2	3	4	5
Adelaide	Weatherbd	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R5/R2/R0 1/1	R5/R1.5/R0 1/1	
	Brk Veneer	R3/Foil/R0 1/1	R3/R2/R0 1/1	R5/Foil/R0 1/1	R5/R2/R0 1/1	R3/R2+F/R0 1/1
	Dbl Brick	R3/30mmP/R0 1/1	R3/R0/R0 1/1	R3/50mmP/R0 1/1	R3/40mmP/R0 1/1	R5/30mmP/R0 1/1
	Conc blk	R3/28mmP/R0 1/1	R3/47mmP/R0 1/1	R3/38mmP/R0 1/1	R5/28mmP/R0 1/1	R5/47mmP/R0 1/1
Brisbane	WB	R3/R1.5/R0 1/1	R3/R2/R0 1/1	R3/Foil/R0 1/1		
	Brk Veneer	R3/Foil/R0 1/1				
	Dbl Brick	R3/R0/R0 1/1				
	Conc blk	R3/R0/R0 1/1				
Canberra	WB	R5/R2/R0 1/1	R3/R2/R0 1/1	R5/R1.5/R0 1/1	R3/R1.5/R0 1/1	Foil+R3/R2/R0 1/1
	Brk Veneer	R5/R2/R0 1/1	R3/R2/R0 1/1	R5/R2+F/R0 1/1	R5/Foil/R0 1/1	R3/R2+F/R0 1/1
	Dbl Brick	R5/50mmP/R0 1/1	R5/40mmP/R0 1/1	R3/50mmP/R0 1/1	R5/30mmP/R0 1/1	R3/40mmP/R0 1/1
	Conc blk	R5/47mmP/R0 1/1	R3/47mmP/R0 1/1	R5/38mmP/R0 1/1	R3/38mmP/R0 1/1	R5/28mmP/R0 1/1
Darwin	WB	R3/R2/R0 2/1	R3/R1.5/R0 2/1	R5/R2/R0 2/1	R5/R1.5/R0 2/1	R3/Foil/R0 2/1
	Brk Veneer	R3/Foil/R0 2/1	R3/R2/R0 2/1	R5/Foil/R0 2/1		
	Dbl Brick	R3/R0/R0 2/1	R3/30mmP/R0 2/1			
	Conc blk	R3/28mmP/R0 2/1	R3/47mmP/R0 2/1	R3/38mmP/R0 2/1	R3/R0/R0 2/1	
Hobart	WB	R5/R2/R0 1/1	R5/R1.5/R0 1/1	R3/R2/R0 1/1	R3/R1.5/R0 1/1	Foil+R3/R2/R0 1/1
	Brk Veneer	R5/R2+F/R0 1/1	R5/R2/R0 1/1	R3/R2+F/R0 1/1	R3/R2/R0 1/1	R5/Foil/R0 1/1
	Dbl Brick	R5/50mmP/R0 1/1	R5/40mmP/R0 1/1	R3/50mmP/R0 1/1	R5/30mmP/R0 1/1	R3/40mmP/R0 1/1
	Conc blk	R5/47mmP/R0 1/1	R5/38mmP/R0 1/1	R3/47mmP/R0 1/1	R3/38mmP/R0 1/1	R5/28mmP/R0 1/1
Longreach	WB	R3/R2/R0 2/1	R3/R1.5/R0 2/1	R3/Foil/R0 2/1	R5/R2/R0 2/1	R5/R1.5/R0 2/1
	Brk Veneer	R3/Foil/R0 2/1	R5/Foil/R0 2/1			
	Dbl Brick	R3/R0/R0 2/1				
	Conc blk	R3/R0/R0 2/1				
Melbourne	WB	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R5/R2/R0 1/1	R5/R1.5/R0 1/1	
	Brk Veneer	R3/Foil/R0 1/1	R3/R2/R0 1/1	R3/R2+F/R0 1/1	R5/Foil/R0 1/1	R5/R2/R0 1/1
	Dbl Brick	R3/50mmP/R0 1/1	R3/40mmP/R0 1/1	R3/30mmP/R0 1/1	R5/50mmP/R0 1/1	R5/40mmP/R0 1/1
	Conc blk	R3/47mmP/R0 1/1	R3/38mmP/R0 1/1	R5/47mmP/R0 1/1	R3/28mmP/R0 1/1	R5/38mmP/R0 1/1
Mildura	WB	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R5/R2/R0 1/1	R5/R1.5/R0 1/1	
	Brk Veneer	R3/Foil/R0 1/1	R3/R2/R0 1/1	R3/R2+F/R0 1/1	R5/Foil/R0 1/1	R5/R2/R0 1/1
	Dbl Brick	R3/50mmP/R0 1/1	R3/40mmP/R0 1/1	R3/30mmP/R0 1/1	R5/50mmP/R0 1/1	R5/40mmP/R0 1/1
	Conc blk	R3/47mmP/R0 1/1	R3/38mmP/R0 1/1	R3/28mmP/R0 1/1	R5/47mmP/R0 1/1	R5/38mmP/R0 1/1
Perth	WB	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R3/Foil/R0 1/1	R5/R2/R0 1/1	R3/R2/R0 2/1
	Brk Veneer	R3/Foil/R0 1/1	R3/R2/R0 1/1	R5/Foil/R0 1/1		
	Dbl Brick	R3/R0/R0 1/1				
	Conc blk	R3/R0/R0 1/1	R3/28mmP/R0 1/1	R3/47mmP/R0 1/1	R3/38mmP/R0 1/1	
Sydney	WB	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R3/Foil/R0 1/1	R5/R2/R0 1/1	R5/R1.5/R0 1/1
	Brk Veneer	R3/Foil/R0 1/1	R3/R2/R0 1/1	R5/Foil/R0 1/1		
	Dbl Brick	R3/R0/R0 1/1	R3/30mmP/R0 1/1	R3/40mmP/R0 1/1	R3/50mmP/R0 1/1	
	Conc blk	R3/R0/R0 1/1	R3/28mmP/R0 1/1	R3/47mmP/R0 1/1	R5/R0/R0 1/1	
Townsville	WB	R3/R1.5/R0 2/1	R3/R2/R0 2/1	R3/Foil/R0 2/1		
	Brk Veneer	R3/Foil/R0 2/1				
	Dbl Brick	R3/R0/R0 2/1				
	Conc blk	R3/R0/R0 2/1				
West Sydney	WB	R3/R2/R0 1/1	R3/R1.5/R0 1/1	R5/R2/R0 1/1	R5/R1.5/R0 1/1	R3/Foil/R0 1/1
	Brk Veneer	R3/Foil/R0 1/1	R5/Foil/R0 1/1	R3/R2/R0 1/1	R5/R2/R0 1/1	
	Dbl Brick	R3/30mmP/R0 1/1	R3/50mmP/R0 1/1	R3/40mmP/R0 1/1	R3/R0/R0 1/1	R5/30mmP/R0 1/1
	Conc blk	R3/47mmP/R0 1/1	R3/28mmP/R0 1/1	R3/38mmP/R0 1/1	R5/47mmP/R0 1/1	R5/28mmP/R0 1/1

Assumptions: 5% discount rate, 40 years , Cooling = Electricity A/C, Heating =Gas, Concrete Floor

Table 34: Medium Single Storey: Combinations within 5% of Max. NPV, any Star rating.

5.8 Sensitivity Analysis

This section explores the sensitivity of the analysis to changes in the base financial assumptions.

5.8.1 Discount, time period, and appliance efficiencies.

Figure 36 shows selected sensitivity runs for the medium sized, single storey, brick veneer house on a concrete slab in four locations – Sydney, Brisbane, Melbourne and Canberra. The parameters changed were:

- Discount rates, from 1% to 11%, in 2% steps.
- Period of analysis from 5 to 70 years, in various steps.
- Energy escalation rate from –2% to + 3%.
- Gas heating efficiencies from 41% (1 AGA Star) to 88% (5 AGA Stars), in Star steps.

The charts show the change in maximum NPV due to variations in the selected parameters, varied one at a time from the base case. The base case is the insulation combination with maximum NPV, for 5% discount rate, 40 years analysis period, zero escalation in real energy costs, and 61% efficiency in gas heating appliances. The vertical axis is the NPV and the horizontal axis is percentage changes in the parameters.

For example a 70 year period is a 75% increase on the base case and in Sydney this causes the NPV to increase by about 15%. A discount rate of 9% is an 80% increase on the base case, ((9/5)-1)*100, and causes the NPV to reduce by about 44% in Sydney.

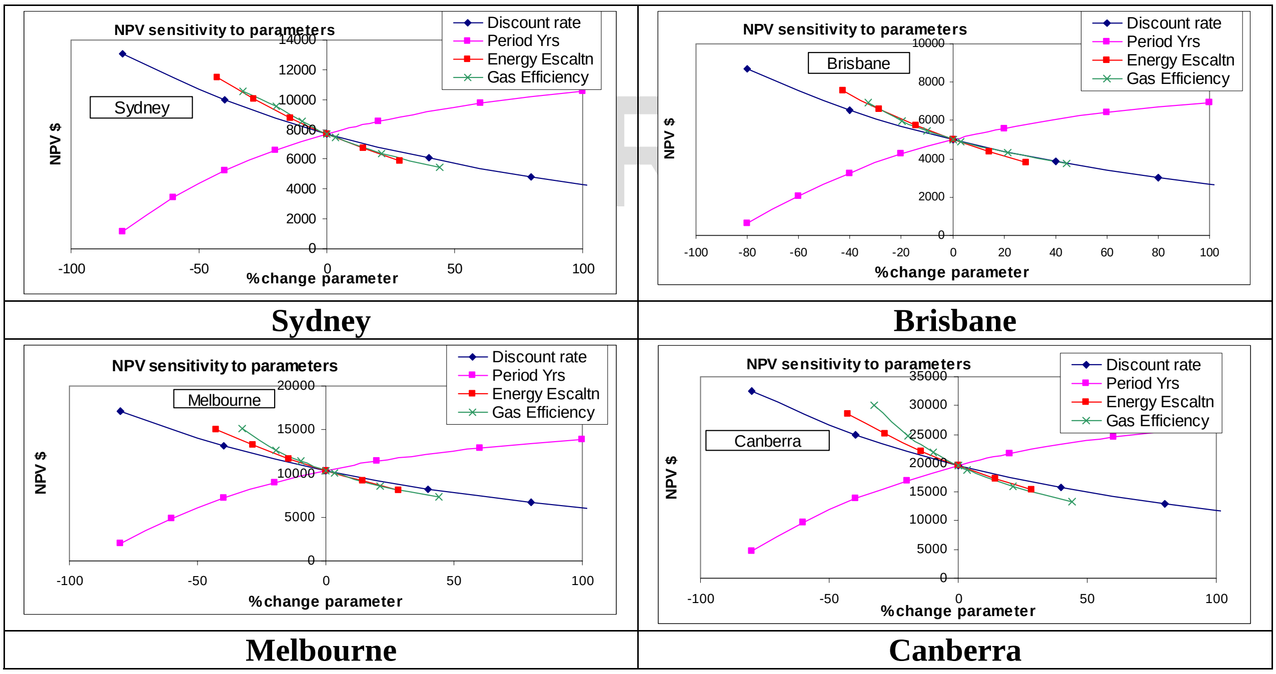


Figure 36 Sensitivity Of NPV To Changes In Various Parameters by Location

The steeper the curves the more sensitive the NPV is to changes in that parameter. The curves indicate the results are sensitive for the following changes:

- **Analysis years, at the shorter analysis periods**: However after about 40 years the curve becomes quite flat.
- **Gas appliance efficiencies in the cooler climates:** A change from a low star rating to higher ratings has a large influence in Canberra and Melbourne, and is not quite as "elastic" in Sydney and Brisbane.

- **Energy price escalation:** At 2% and 3% escalation the change to NPV is large in all locations. Note escalation increases are almost equivalent, in terms of the present value formula, to reducing the discount rate by the same amount.

Note that with all these changes the NPV remains positive, but in some cases the insulation combination to achieve the NPV changes. For example, in Canberra the combination reduces from R5/R2/R0 1/1 to R3/Foil/R0 1/1 for high discount rates (above 7%), low years of analysis (below 20 years), and high gas heater efficiencies (above 74%). In the other three locations the only change is for the 5 years analysis period, when the insulation combination with maximum NPV is R1/Foil/R0, down from R3/Foil/R0 for the base case. These are minor changes in the amount of insulation, and suggest that the maximum NPV insulation combinations are fairly insensitive to changes in these parameters. However other locations, and house types, would also need to be tested for sensitivity.

5.8.2 Occupancy hours

The effect of this parameter was examined for one house type. A change in the occupancy hours, from 17 hours to 8 hours, has some effects on maximum NPV insulation combinations. In the hot climates, Darwin, Longreach and Townsville, less insulation achieves the maximum NPV, down from R3/Foil/R0 Tint/Nil to R0/Foil/R0 Plain/Nil. Also in the cool climates, Canberra and Hobart, less insulation achieves the maximum NPV, down from R5/ R2/ R0 Plain/ Nil to R3/R2/R0 Plain/Nil. There was no change in the insulation combination for other locations for the brick veneer, concrete slab-on-grade floor house.

5.8.3 Glazing costs

Table 34, combinations with 4 Stars or better and a positive NPV, was duplicated for a 30% reduction in the cost of double glazing. The reason for this trial is that in the event of mandatory thermal insulation in housing there may be economies of scale, and price reductions, in the supply of double glazing window units. The effect of this change was that double glazing appeared for Brisbane and Longreach, having a positive NPV and giving 4 Stars house rating or better. These regions joined all the other locations in supporting the use of double glazing. This result needs to be explored for other house designs and sensitivity to the size of the hypothetical price change.

5.8.4 Shading costs

The full cost of the shading is included in the default selections of the analysis tool, and the cost of shading may be a reason why it is not a viable option for some design and location choices. An analysis of Chart 5 in the analysis tool shows that eaves, with other insulation combinations, have a positive NPV, and 4 Stars or more, for the first two house designs, on a concrete slab, in all locations except Canberra, Darwin, Longreach, Perth and Townsville. The latter locations do not achieve the 4 Star rating so changing the cost of eaves is not an issue, if a 4 Star rating is the selection criteria.

However for verandahs, changing their cost did affect their viability in four locations. If the full cost is included then they did not achieve a positive NPV in any location for the first two designs on a concrete slab. However a reduction of cost by 50% did give a positive NPV and achieve 4 Stars or better in Adelaide, Darwin, Longreach, and Perth. This result is for brick veneer on concrete slab only, and needs to be explored for other designs and wall types.

There may be valid reasons for not allocating the full cost of shading to energy efficiency for the financial analysis, as shading also performs other critical roles. For example, eaves and verandah greatly assist in weathertightness around windows and doors, they may be used for clothes drying, they may form an important ‘outdoor’ space for enjoyment when temperatures are high or rain is heavy, and verandahs provide a transition area into the house in the wet season.

5.9 CO_2 savings

The CO_2 supply curve, Figure 34, shows the unit cost per kg CO_2 saved plotted against annual CO_2 savings for one house. The vertical axis is the NPV divided by the CO_2 savings. However, one important question is what volume of CO_2 savings should be used as the divisor?

The choices are:

- Annual CO_2 savings.
- Total CO_2 savings over the analysis period, e.g. over 40 years.
- Discounted CO_2 savings over the analysis period.

The first choice does not recognise CO_2 savings after the first year. The second choice assumes that CO_2 savings are equally valued in subsequent years. The third choice assumes that immediate CO_2 savings are of more value than distant savings. The third choice, is preferred, i.e. discounted CO_2 savings are used as the divisor. The reasoning is as follows:

Suppose decision makers wish to increase the amount of insulation beyond that indicated by the combination with the maximum NPV, or the combination closest to zero NPV. How can they justify that decision in financial terms? They can justify it in terms of a normal cost-benefit analysis in which a value is put on CO_2 savings, say a hypothetical world trading price in $US per tonne of carbon. The argument is that more is spent now on insulation to reduce the future expenditure on carbon emission rights. This purchase of carbon rights is expected to be in blocks, possibly for periods of 5 years, and occurs at year 0, 5, 15, 20, and so on. Hence this expenditure is similar to any other future cash flow, and needs to be discounted. In present value terms the equation for an individual house is given in Equation 9:

$$\$_{EnergyEfficiency} - PV_{EnergySavings} - PV_{CO_2Savings} = 0$$

Equation 9

In other words, this equation suggests that the justifiable amount of expenditure on energy efficiency options (insulation, glazing or shading) is equal to the value of the discounted energy savings plus the discounted value of CO_2 savings, over the analysis period e.g. 40 years. CO_2 savings are discounted because they represent a cash flow over a period of years as in Equation 10.

$$PV_{CO2Savings} = \sum_{t=1}^{N} \frac{P_{CO_2} \times Vol_{CO_2Savings}}{(1+r)^t}$$

Equation 10

where P_{CO2} = Unit price of CO_2 emissions ($/kg CO_2)

$Vol_{CO2Savings}$ = kg of CO_2 saved per year

It is likely that the unit price of CO_2 emissions will change over time. However for simplicity we assume it remains constant. Hence in Equation 10 we are effectively discounted the volume of CO_2 savings. We do not know the hypothetical trading price for CO_2 emissions. Instead the financial tool shows what the trading price needs to be at various insulation levels, to satisfy Equation 9.

How are the points on the CO_2 supply curve obtained? Firstly all insulation combinations are ranked in ascending order of $/kg CO_2 saved. The most negative value is the starting point and its kg of CO_2 saved is recorded. Then combinations are sequentially checked and tested to see if they are "outer envelope" points, and if so they are recorded in the supply curve sequence. The test is whether their kg of CO_2 saved exceeds the previous point in the supply curve sequence. Many combinations are passed over as their kg of CO_2 saved indicates they lie inside the envelope. Eventually the last point in the sequence is recorded, usually one with maximum insulation and additional glazing and shading, and the supply curve is complete. This process is automated and acts when the CO_2 graphing buttons are pressed on the main menu.

5.10 Summary Results

Section 14 provides an example of summary output available from the financial analysis tool. It takes the selected results from the CO_2 charts, and presents them for each location, for each house design, floor type and wall construction. They have been sorted into location order, and it can be seen that a relatively small number of energy efficiency combinations met the specific requirements for each location, regardless of house design, floor type or wall construction.

6. ADDITIONAL MODEL STUDIES

This section provides results form additional NatHERS sensitivity studies and the modelling comparisons undertaken in EnCom2 and DOE2.

6.1 Hot Climate "Free-Running" Comfort Study

Despite recent survey results showing that 85% of Darwin houses possess at least one air conditioner (EPA, 2000), some concern has been expressed by stakeholders in the north of Australia that building code energy efficiency requirements based on energy performance for air conditioned (i.e. refrigeratively cooled) dwellings could be counterproductive in "free-running" houses which rely on selective ventilation to maintain acceptable comfort. Such designs use high volume ventilation to both remove excess heat from the dwelling and to generate internal breezes which have a physiological and psychological cooling effect on the occupants (Szokolay, 2000, ISO 1994).

This concern is two fold. Firstly, there is the perceived potential for insulation to be counterproductive when applied to a competent free-running design. Secondly, there is a concern that designing to reduce the energy consumption for cooling, especially by a reduction in window size, will reduce the available ventilation rate and its internal breeze effects. This could impair the intrinsic comfort of the design and result in the more common purchase and more frequent use of a cooler such that the average energy consumption of new homes actually increases.

While noting the potential for inappropriate regulation to impair the application of good free-running design, this study does not attempt to resolve that concern as its scope does not include modifications to window size nor cross-ventilation effectiveness in the main parametric body of work (although limited investigations are described in Section 6.2). However, the question of the potential for insulation to be counterproductive has been investigated through a suite of targeted simulations using the CSIRO's CHENATH[xv] software.

6.1.1 Dwellings Simulated in Darwin

All six dwelling forms were simulated for this comfort study in 3 distinct configurations – firstly without any eaves or verandahs (as parametrically simulated in the bulk runs, see Section 4.1) and secondly in two configurations with the eaves and verandahs as originally designed (in contrast to the base case versions used in the bulk NatHERS runs which had no eaves or verandahs). Further, particular attention was directed at Houses 5 and 6 (the "Cross Ventilated Tropics" and "Passive Solar" respectively) as they represent extremes for a hot humid climate.

The Cross Ventilated Tropics house, representing the archetypal free-running house with verandahs protecting the large window areas on the long north and south sides was focussed on for varying the ventilation rates. This was to test the effectiveness of insulation in the context of the selection of windows with larger than conventional openable areas and of an elevated floor level.

The Passive Solar, representing a highly directionally-sensitive archetype (designed for the cool climate) was focussed on for varying the orientation. This was to test the potential for added insulation to be counterproductive in instances of truly bad design for climate with large scantily shaded window areas facing east and west.

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xv CHENATH is the simulation "engine" of the NatHERS software suite.

6.1.2 Simulation Technique

NatHERS uses a simplified routine for simulating ventilation. The user sets the base rate as either poor or good by selecting No or Yes in answer to the query:

"Can doors or windows be opened on opposite sides of the house to provide cross-flow ventilation?"

Based on that input the programme selects parameters a and b in the empirically established approximate relationship given in Equation 11:

$$\text{Ventilation} = \text{a} + \text{b}\sqrt{}\, Speed$$

Equation 11

with Ventilation being expressed in Air Changes per Hour (ACH) and wind speed in metres per second (measured at standard height and in clear terrain by the Bureau of Meteorology). The relationship is not sensitive to wind direction (the climate files do not include that data) nor to window design (such as side hung casements working as breeze scoops). It is, however, constrained to not exceed 40 ACH as at such a ventilation rate, the breezes inside may create nuisance as well as cooling effect and it is assumed that the occupants would then choose to partially close the windows/doors to avoid that nuisance.

With the selection of "Yes" by the user, the parameters are set as in Equation 12:

$$\text{Ventilation} = 3.0 + 10.0\sqrt{}\, Speed$$

Equation 12

which are the values used for all these runs except for the in-depth analysis of the Cross Ventilated Tropics.

The dwellings were simulated with neither heating nor cooling, with the output being hourly temperatures in each of the zones. The results for the living zone were then analysed for their comfort implications.

In the case of the Cross Ventilated Tropics, the parameters were set at double those in the standard relationship to reflect the advantage of the house being high set and with greater openable areas than assumed in the standard relationship. Parameter "a" was also set at 40 so that results for continuous maximum ventilation could be evaluated. Such a ventilation regime might be achieved with floor to ceiling openings and ceiling fans operated whenever breezes were inadequate (i.e. under 2.9 m/sec in the case of the doubled relationship above). The effect of even higher rates, known to be acceptable in free-running designs by, for example, using louvre (jalousie) windows to direct the internal breeze up to the ceiling to reduce its nuisance effects while maximising its potential to flush the warmest air from the house, were not simulated due to the 40 ACH constraint currently built into the software.

6.1.3 Definition of "Comfort" and its Input Parameters

Comfort in free-running houses is a matter of some controversy despite the widespread acceptance of ISO 7730 1994 and its derivative American quasi-standard (ASHRAE, 1999) in the air conditioning design industry. There is for instance, no consensus on the effects of acclimatisation (the Standards posit that there is none) and there is also some doubt that householders in hot climates expect/demand "comfort" (however defined) as distinct from avoidance of heat stress. The ongoing debate is covered thoroughly by Szokolay (2000).

For the purposes of this study, the algorithms for calculating PMV[xvi] in ISO 7730 were used because they are well accepted by the building industry and because they include allowance for all four key parameters of air temperature, mean radiant temperature, humidity and air speed[xvii] in addition to the physiological ones of metabolic rate and clothing insulation. As ISO 7730 is restricted to moderate thermal environments, PMV values beyond +3 are unreliable but were accepted in this study in the belief that the inaccuracy of the algorithms above that range is less than the distortion involved in capping the PMV at +3, which assumes that conditions inside a free-running house are never thermally immoderate.

CHENATH does not actually calculate any of the four parameters, but it does calculate a quasi-environmental temperature, which is an amalgam of the mean radiant temperature (MRT)[xviii] and air temperature, on an hourly basis. Accordingly, those hourly output temperatures were used for both the MRT and air (dry bulb) temperature. Additionally, it was assumed that with high ventilation rates the indoor humidity will be the same as the outdoor and hence can be read from the climate file and converted to the units required by the ISO algorithms. The air speed was taken as 0.5 m/sec which is a significant but non-nuisance internal breeze which can easily be produced with a ceiling fan where the wind is insufficient.

The physiological parameters of clothing and metabolic rate were set at 0.4 Clo (e.g. underwear, light dress with sleeves, sandals) and 1.2 met (e.g. seated sedentary work) respectively which would be appropriate for social situations in warm to hot weather.

6.1.4 Interpretation of Results

The detailed results of the suite of 33 simulations (6 dwellings plus 2 ventilation variants of House 5 and 3 orientation variants of House 6 – all times 3 thermal enhancement levels) is compiled into (dis)comfort bands and set out in Table 35 and Table 36. The thermal enhancement levels are the same as those in the Comparative Study (see Section 4.6) and titled Bare (no insulation), Mid (some insulation) and Better (well insulated). Values in the "Over +3" band can be taken as occurrences of heat stress.

The hourly PMV values were then collated by PMV bands for indications of the variability over the year and compiled for each dwelling into three criteria:

1. **Sum** adding each of the 8,760 PMV values as an indicator of (dis)comfort
2. **Count** counting each PMV value (as a check value for the other two) to indicate the unweighted frequency of occurrences
3. **Mean** dividing the Sum by the Count to indicate the strength of bias toward thermal neutrality within each PMV band

The PMV values are treated equally irrespective of the time of day. This is not an assumption that has current consensus as there is a case for treating night and day differently. For example, northerners in free-running houses are arguably more sensitive to heat discomfort at night than during the day but with good ventilation and adequate sun protection for the windows to avoid substantial heat build-up, such re-analysis is unlikely to overturn the conclusions reached here.

The results in the negative PMV bands are included for completeness and reality checking, but can otherwise be ignored as such instances would routinely be obviated in practice by closing the windows, turning the fan down or off and/or adding more clothing.

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xvi PMV = Predicted Mean Vote on a 7 point scale from +3 = hot through 0 = neutral to –3 = cold.

xvii Some simplified relationships derived from air temperature and speed alone give credibly reliable results in some climates (Szokolay, 2000).

xviii MRT is the solid angle area weighted average temperature of the walls, ceiling and floor of a room. In an insulated and highly ventilated room it will tend to equal the air temperature but will be somewhat higher in the day in the absence of insulation to isolate the inner surfaces from the sol-air effects.

		SUM			COUNT			MEAN		
Design	**PMV**	**Bare**	**Mid**	**Better**	**Bare**	**Mid**	**Better**	**Bare**	**Mid**	**Better**
House 1	Under -2	-394	0	0	170	0	0	-2.32	0.00	0.00
	-2 to -1	-1507	0	0	1030	0	0	-1.46	0.00	0.00
	-1 to +1	143	2179	2301	4256	4156	4464	0.03	0.52	0.52
	+1 to +2	2715	6170	5946	1794	4267	4172	1.51	1.45	1.42
	+2 to +3	3310	709	258	1359	337	124	2.43	2.10	2.08
	Over +3	491	0	0	151	0	0	3.25	0.00	0.00
	Under 0	-2837	-33	-47	3254	313	409	-0.87	-0.11	-0.12
	Over 0	7595	9091	8553	5506	8447	8351	1.38	1.08	1.02
	Totals	**10431**	**9124**	**8600**	**8760**	**8760**	**8760**			
House 2	Under -2	-1466	0	0	563	0	0	-2.61	0.00	0.00
	-2 to -1	-1510	0	0	1045	0	0	-1.44	0.00	0.00
	-1 to +1	-13	2065	2251	3907	3872	4281	0.00	0.53	0.53
	+1 to +2	2540	6593	6273	1666	4536	4361	1.52	1.45	1.44
	+2 to +3	3193	742	247	1310	352	118	2.44	2.11	2.09
	Over +3	923	0	0	269	0	0	3.43	0.00	0.00
	Under 0	-3903	-19	-31	3595	225	327	-1.09	-0.09	-0.10
	Over 0	7570	9419	8803	5165	8535	8433	1.47	1.10	1.04
	Totals	**11473**	**9439**	**8834**	**8760**	**8760**	**8760**			
House 3	Under -2	-1117	0	0	433	0	0	-2.58	0.00	0.00
	-2 to -1	-1427	0	0	982	0	0	-1.45	0.00	0.00
	-1 to +1	54	1943	2123	3830	3618	4036	0.01	0.54	0.53
	+1 to +2	2508	6692	6512	1642	4560	4480	1.53	1.47	1.45
	+2 to +3	3848	1238	513	1562	582	244	2.46	2.13	2.10
	Over +3	1047	0	0	311	0	0	3.37	0.00	0.00
	Under 0	-3422	-21	-35	3301	227	321	-1.04	-0.10	-0.11
	Over 0	8335	9894	9183	5459	8533	8439	1.53	1.16	1.09
	Totals	**11757**	**9915**	**9219**	**8760**	**8760**	**8760**			
House 4	Under -2	-283	0	0	123	0	0	-2.30	0.00	0.00
	-2 to -1	-1194	0	0	821	0	0	-1.46	0.00	0.00
	-1 to +1	595	2021	2223	4608	3496	3914	0.13	0.58	0.57
	+1 to +2	3480	6981	6553	2380	4920	4698	1.46	1.42	1.39
	+2 to +3	1912	728	308	800	344	148	2.39	2.12	2.07
	Over +3	90	0	0	28	0	0	3.18	0.00	0.00
	Under 0	-2304	-12	-19	2832	150	211	-0.81	-0.08	-0.09
	Over 0	6904	9742	9101	5928	8610	8549	1.16	1.13	1.06
	Totals	**9208**	**9754**	**9120**	**8760**	**8760**	**8760**			
House 5	Under -2	-1561	0	0	585	0	0	-2.67	0.00	0.00
	-2 to -1	-1455	-23	-19	1013	21	17	-1.44	-1.14	-1.12
	-1 to +1	-71	1634	1715	3648	4144	4268	-0.02	0.39	0.40
	+1 to +2	1689	5359	5627	1119	3670	3882	1.51	1.46	1.45
	+2 to +3	3293	2040	1275	1305	925	593	2.52	2.21	2.15
	Over +3	3889	0	0	1090	0	0	3.57	0.00	0.00
	Under 0	-3901	-276	-266	3473	849	854	-1.12	-0.33	-0.31
	Over 0	9685	9285	8864	5287	7911	7906	1.83	1.17	1.12
	Totals	**13586**	**9561**	**9130**	**8760**	**8760**	**8760**			
House 6	Under -2	-1492	0	0	564	0	0	-2.65	0.00	0.00
	-2 to -1	-1454	0	0	1009	0	0	-1.44	0.00	0.00
	-1 to +1	-53	2005	2216	3687	3279	3742	-0.01	0.61	0.59
	+1 to +2	1912	7540	6980	1256	5184	4942	1.52	1.45	1.41
	+2 to +3	3692	629	158	1472	297	76	2.51	2.12	2.08
	Over +3	2706	0	0	772	0	0	3.51	0.00	0.00
	Under 0	-3838	-7	-11	3457	93	141	-1.11	-0.09	-0.09
	Over 0	9149	10181	9365	5303	8667	8619	1.73	1.17	1.09
	Totals	**12987**	**10188**	**9376**	**8760**	**8760**	**8760**			

Table 35: Compiled hourly comfort data for six free-running dwellings in Darwin

Interestingly, in all six dwellings with conventional ventilation rates and suitably oriented, Table 35 shows that both levels of thermal enhancement (Mid and Better) eliminated instances of heat stress (defined as PMV > +3 and mostly occurring during the day). Also, encouragingly, in all eleven cases shown in Table 35 and Table 36, including the mis-oriented Passive Solar (i.e. facing west) the performance of the Mid insulated house was always superior to the Bare case, and the Better was always superior to the Mid case. This was as measured by the more moderate but more important criterion of discomfort in the +2 to +3 PMV band (i.e. warm to hot). Here, by both the Mean PMV and the frequency of occurrence (Count), the ranking of the relative merits of thermal enhancement were the same in the free-running case as they were for the air-conditioned case.

		SUM			COUNT			MEAN		
Design	**PMV**	**Bare**	**Mid**	**Better**	**Bare**	**Mid**	**Better**	**Bare**	**Mid**	**Better**
House 5a	Under -2	-1604	-1153	-1089	602	454	430	-2.66	-2.54	-2.53
2 times ventilation	-2 to -1	-1565	-1748	-1570	1088	1202	1075	-1.44	-1.45	-1.46
	-1 to +1	-85	129	161	3784	4421	4476	-0.02	0.03	0.04
	+1 to +2	1996	2709	2883	1311	1831	1959	1.52	1.48	1.47
	+2 to +3	3541	1967	1895	1412	835	810	2.51	2.35	2.34
	Over +3	1923	53	32	563	17	10	3.42	3.12	3.10
	Under 0	-4092	-3901	-3660	3647	3773	3615	-1.12	-1.03	-1.01
	Over 0	8298	5858	5972	5113	4987	5145	1.62	1.17	1.16
	Totals	**12390**	**9759**	**9631**	**8760**	**8760**	**8760**			
House 5b	Under -2	-1515	-1050	-1018	569	412	402	-2.66	-2.55	-2.53
100 times ventilation	-2 to -1	-1851	-2166	-2204	1285	1496	1523	-1.44	-1.45	-1.45
40 capped	-1 to +1	-50	83	94	4072	4642	4776	-0.01	0.02	0.02
at air changes	+1 to +2	2396	2464	2463	1576	1695	1704	1.52	1.45	1.44
	+2 to +3	2802	1162	784	1161	512	351	2.41	2.27	2.23
	Over +3	312	9	13	97	3	4	3.21	3.00	3.00
	Under 0	-4357	-4303	-4341	3945	4178	4243	-1.10	-1.03	-1.02
	Over 0	6451	4805	4472	4815	4582	4517	1.34	1.05	0.99
	Totals	**10807**	**9108**	**8813**	**8760**	**8760**	**8760**			
House 6e	Under -2	-1461	0	0	550	0	0	-2.66	0.00	0.00
Passive solar house	-2 to -1	-1373	0	0	950	0	0	-1.45	0.00	0.00
orientated as shown	-1 to +1	-38	1674	1936	3356	2860	3379	-0.01	0.58	0.57
(e.g. e = East)	+1 to +2	1718	6924	6978	1140	4760	4830	1.51	1.45	1.44
	+2 to +3	3456	2503	1185	1374	1137	550	2.52	2.20	2.15
	Over +3	5136	9	3	1390	3	1	3.69	3.00	3.00
	Under 0	-3639	-10	-16	3187	119	185	-1.14	-0.08	-0.09
	Over 0	11077	11120	10117	5573	8641	8575	1.99	1.29	1.18
	Totals	**14716**	**11129**	**10133**	**8760**	**8760**	**8760**			
House 6s	Under -2	-1522	0	0	575	0	0	-2.65	0.00	0.00
	-2 to -1	-1483	0	0	1029	0	0	-1.44	0.00	0.00
	-1 to +1	-67	2247	2469	3761	3970	4410	-0.02	0.57	0.56
	+1 to +2	1976	6372	5937	1296	4545	4305	1.52	1.40	1.38
	+2 to +3	3723	510	93	1482	245	45	2.51	2.08	2.07
	Over +3	2150	0	0	617	0	0	3.48	0.00	0.00
	Under 0	-3919	-19	-26	3529	205	271	-1.11	-0.09	-0.10
	Over 0	8695	9148	8526	5231	8555	8489	1.66	1.07	1.00
	Totals	**12614**	**9167**	**8553**	**8760**	**8760**	**8760**			
House 6w	Under -2	-1466	0	0	553	0	0	-2.65	0.00	0.00
	-2 to -1	-1376	0	0	953	0	0	-1.44	0.00	0.00
	-1 to +1	-46	1750	1998	3426	2959	3478	-0.01	0.59	0.57
	+1 to +2	1604	6931	6652	1064	4760	4664	1.51	1.46	1.43
	+2 to +3	3308	2384	1377	1307	1040	618	2.53	2.29	2.23
	Over +3	5483	3	0	1457	1	0	3.76	3.00	0.00
	Under 0	-3671	-9	-13	3250	111	161	-1.13	-0.09	-0.09
	Over 0	11178	11076	10041	5510	8649	8599	2.03	1.28	1.17
	Totals	**14848**	**11086**	**10054**	**8760**	**8760**	**8760**			

Table 36: Hourly comfort data for two archetypal free-running dwellings in Darwin

6.1.5 Comfort Study - Conclusions and Recommendations

This comfort study supports the strategic contention that, for a given design, thermal enhancements which increase the energy efficiency when the dwelling is air-conditioned, will also improve the dwelling's intrinsic comfort when operated without cooling but with ceiling fans available to create internal breezes whenever the wind is inadequate in that regard. This suggests the conclusion that having separate requirements in the BCA for air-conditioned and free-running houses may be an unnecessary complication.

This interim conclusion needs to be confirmed by a more thorough analysis of the diurnal patterns of the (dis)comfort and with diurnal changes to the metabolic rate and clothing levels that agree more rigorously with the daily patterns of real occupants. Also, some check on the effect of diffuse irradiation entering through the glazing and creating an effective increase in Mean Radiant Temperature is indicated.

6.2 Modelling Sensitivity Studies

Additional NatHERS sensitivity studies have been undertaken to investigate the importance of glazing area, occupancy schedule, the use of curtains and blinds, carpet, natural ventilation and infiltration. Table 26 summarises these studies, and the type of investigation undertaken setting out the parametric changes made to the houses in turn. No combinations of these parametric changes were investigated – each was only applied to the three levels of thermal enhancement as base cases or archetypes.

Variations	Comment or Definition
Glazing area	Subtract 1 m² from a window (reduce width) to a conditioned area on each of the 4 façades. Where there is choice, subtract from the Living Zone before Sleeping before Other. Where there is no conditioned zone, subtract from the unconditioned Zone.
Occupancy	Make the heating and cooling plant operate continuously with thermostat control.
Curtains and blinds	In Darwin, add Venetian blinds. In West Sydney and Canberra, add drapes with pelmets.
Carpet	Remove Carpet from Living, Bed & Other Zones
Natural Ventilation	Double the ventilation rate only in the Cross Ventilated Tropic house in both calm and breeze conditions.
Infiltration	Add an Exhaust Fan w/o Damper to the Base house. Delete weatherstripping to the Mid and Better CO_2 houses.

Table 37: Sensitivity Studies

The sensitivity studies were undertaken on each of three house types for each of three climates as set out in Table 38:

House 2 (Medium single storey, brick veneer walls and slab-on-ground concrete floor)	Darwin (hot)
House 3 (Large double storey, brick veneer walls and slab-on-ground concrete floor)	West Sydney (temperate)
House 5 (“Cross Ventilated Tropics”, Cross ventilated tropics, open undercroft with a timber floor and weatherboard walls)	Canberra (cool)

Table 38: House types and Climates for the Sensitivity Studies

The three variations in energy efficiency options used in the comparative study (see Section 4.8) were used: titled Bare (Base House), Mid (some Energy Efficiency options); Better (options approximating maximum CO_2 savings with a positive NPV under base assumptions). These archetypes, however, differ from those used in the comparison study in that the shading in the Mid and Better cases is ‘as drawn’[xix] (to better reflect industry practice rather than parametric neatness and convenience) and the Better archetype House 5 in Darwin was fitted with tinted (toned) single glazing - not double clear glazing.

6.2.1 Baselines of Results

For this sensitivity study, the cited parameter was changed and the revised simulation results compared with those of the archetype from the bulk simulations as set out in Table 39, Table 40

[xix] House 5 ‘as drawn’ includes a widely spaced pergola over much of the southern windows. As the evaluation of the effects of landscaping is beyond the scope of this study and because the pergola would have negligible shading impact while bare, it was omitted from the simulations reported on here.

and Table 41. The results of these simulations are summarised in the graphs set out in Figure 37 through Figure 42, and discussed under the respective headings in Section 6.2.2 following. When comparing these results with those of the analysis tool, it must be borne in mind that these values are heat and cool demanded, rather than the energy consumed (bought) cited by the analysis tool which allows the user to select appliance efficiencies for the heater and cooler.

Location	Configuration	Total Energy	Heating Energy	Sensible Cooling	Latent Cooling
Canberra	Bare	929.8	735.6	191.2	3.0
Darwin	Bare	1,070.6	0.2	887.3	183.0
West Sydney	Bare	611.8	340.8	257.4	13.7
Canberra	Mid	308.8	240.9	66.2	1.7
Darwin	Mid	595.7	0.0	475.7	120.0
West Sydney	Mid	189.3	99.5	83.3	6.6
Canberra	Better	193.4	143.0	48.9	1.5
Darwin	Better	486.1	0.0	374.7	111.4
West Sydney	Better	104.2	42.4	56.5	5.3

Table 39: Annual Energy Demand (MJ/m²) for House 2 Archetypes

Location	Configuration	Total Energy	Heating Energy	Sensible Cooling	Latent Cooling
Canberra	Bare	869.8	675.3	191.3	3.2
Darwin	Bare	1,212.6	0.2	1,023.5	188.9
West Sydney	Bare	586.0	301.0	270.3	14.6
Canberra	Mid	315.2	231.3	81.8	2.1
Darwin	Mid	729.9	0.0	600.3	129.6
West Sydney	Mid	213.6	90.0	115.4	8.2
Canberra	Better	201.9	137.1	63.1	1.8
Darwin	Better	553.3	0.0	435.6	117.7
West Sydney	Better	130.2	37.3	85.9	7.1

Table 40: Annual Energy Demand (MJ/m²) for House 3 Archetypes

Location	Configuration	Total Energy	Heating Energy	Sensible Cooling	Latent Cooling
Canberra	Bare	1,134.4	846.0	282.7	5.8
Darwin	Bare	1,390.9	0.3	1,183.5	207.1
West Sydney	Bare	804.9	393.7	391.1	20.1
Canberra	Mid	635.3	571.0	61.2	3.1
Darwin	Mid	643.6	0.1	515.6	128.0
West Sydney	Mid	378.8	273.1	96.1	9.6
Canberra	Better	464.9	418.9	43.1	2.9
Darwin	Better	517.2	0.0	396.9	120.3
West Sydney	Better	253.9	184.2	61.7	8.0

Table 41: Annual Energy Demand (MJ/m²) for House 5 Archetypes

6.2.2 Interpretation of Results

Carpet

For the bulk simulations of these three house types, carpet was included on all floor areas except kitchen, family room and wet areas. For this sensitivity study, the carpet and other floor coverings were removed and the revised simulation results compared with those of the archetype (see Figure 37). Carpet adds the thermal insulation equivalent of R 0.4 (BRANZ 1995), which particularly in the case of the 'uninsulated' suspended timber floor may be a significant proportion of the total floor thermal performance – in these examples only the energy use of House 5 is examined with a suspended timber floor (see Section 4.8).

As expected, the removal of the carpet leads to an increase in heating energy consumption in virtually all cases (except Darwin which requires no heating) and a reduction in cooling energy in all cases. The case of House 5 is worth comment in that its very large heating savings are modest in the Bare case relative to the Mid and Better cases. This is likely to be a passive solar effect. The bare case has no eaves/verandas while the other two have the full shading as drawn. Thus in the Bare case the large northerly windows are working to winter benefit to displace much of the need for active heating in both the carpeted and uncarpeted configurations.

It should be noted that the BCA is not expected to require carpet irrespective of its energy merits. The house models in the bulk runs used carpet, where it might normally be installed shortly after practical completion, to provide energy demand values with a closer relationship to normal practice. This sensitivity study examines the house performance as though it were occupied with no floor coverings beyond the expected code requirement - i.e. no carpet. The runs confirmed that carpet plays an important role in improving the energy efficiency of conventional houses (House 6 - Passive Solar is not included in this sensitivity study).

In the heating situation, the carpet provides less thermal insulation than dished foil in energy terms. The BRANZ Insulation Guide (BRANZ 1995) gives carpet and underlay an indicative R-value of 0.4 although the practical range of values available is quite wide, while drooped (dished) foil is generally regarded as at least R 0.9. Foil costs $\$4.05/m^2$ whilst under slab insulation is $\$10/m^2$ (see Table 10), so carpet is a somewhat more expensive way of achieving a lower R-value and is clearly selected for more than its thermal enhancement. With no carpet in the house, then foil / polystyrene would prove even more beneficial than is shown in the bulk runs.

Since the removal of carpet is almost universally detrimental for heating and the presence of carpet is common for the life of most homes outside the tropics, the results from the bulk runs are confirmed as being indicative of results likely to be recorded in the field for the majority of Australian homes.

Curtains and Blinds

For the bulk simulations of these three house types, all windows and glazed doors were assumed to be bare (i.e. they were without internal window furnishings. For this sensitivity study, the glazed areas were fitted with drapes and pelmets in West Sydney and Canberra and with Venetian blinds in Darwin and the revised simulation results compared with those of the archetype (see Figure 38).

As expected, the addition of the window furnishings has a marked energy saving effect relative to the bare glass. In Canberra and Sydney, most of the benefit is in heating and that benefit is more modest in the case of the Better configuration as that includes double glazing in its archetype. In Darwin the benefit is even more marked for cooling except for the Better case (which has tinted (toned) single glazing) and in House 5 where the extensive verandahs in the Mid and Better cases render the shading benefit of the blinds almost superfluous.

Since the addition of window furnishings is found to be beneficial in virtually all cases, it should be borne in mind that the energy cost savings found in the bulk runs for high performance windows will be greater than what might be realised in the field. The Venetian blinds added in Darwin are indicative of occupant fit-out whereas the pelmets and drapes in Canberra and West Sydney give an enhancement rarely achieved in practice due to the popularity of vertical Venetian blinds in those locations – as such they represent an upper bound to the correction that might reasonably be applied.

The standard operation parameters for the curtains and blinds in the NatHERS software were used in all cases and these are set out in Table 42. The results, and conclusions, only apply to houses where this 'perfect' operating pattern is followed. This is particularly important for cooling in hot daytime regions, and heating in cold night time regions (ignoring any passive solar benefits) where 'imperfect' operation by real occupants will reduce the advantage indicated by these results.

Routine Curtain Operating Times (24 hour clock)	Opened: 07:00	Closed: 18:00
Outdoor Conditions Above Which Curtains Drawn (both conditions must apply)	Temperature (°C) 28.0	Incident Solar (W/m²) 200.0

Table 42: Operation parameters for curtains and Venetian blinds

Glazing Area

For the bulk simulations of these three house types, all windows and glazed doors were input in accordance with the drawings while the eaves/verandahs were changed parametrically by preset sizes from a zero shaded base case. For this sensitivity study, the glazed areas were reduced by 1.0 m² on all four sides as detailed in Table 26 (reduced in width, not in height, to ensure that the shading conditions were unchanged) and the revised simulation results compared with those of the archetype (see Figure 37).

In most cases a reduction in glass area (on all four facades) resulted in a reduction in energy demand of both heating and cooling. Houses 3 and 5 show a slight increase in heating energy in Canberra, which is likely to be due to lost solar heat gain, especially in the Bare case. In Canberra and West Sydney it saved around 20 MJ/m² per year or 5 MJ/m² per square meter of glazing reduction. In the Better case, with its double glazing, the saving was only half that. In Darwin, the saving was around 40 MJ/m² or 10 MJ/m² per square metre of glass. It is important to note that these results ignore the reduction of daylighting and cross ventilation that such a change would actually entail as the software is currently unable to evaluate these aspects (see Ventilation below for further comment).

It is worth noting that glazing is always more expensive than good walls - glazing base case $207.20 $/m² (Table 11) versus brick veneer $137.00 $/m², and 200 thick, hollow blockwork is only $82/m². Accordingly reduced glazing is always a cost effective way of saving energy (with the obvious exception not analysed here of added north glazing in climates with significant heating needs). It can also be concluded that glazing area is not currently determined by cost optimisation and accordingly the setting of maxima for energy saving reasons will need to keep the other factors in mind.

Infiltration

For the bulk simulations of these three house types, no items of major infiltration potential were included. For this sensitivity study, the infiltration rate was increased in the Bare house by the addition of an undamped exhaust fan and in the Mid and Better case by removal of weatherstripping as detailed in Table 26 and the revised simulation results compared with those of the archetype (see Figure 40).

As expected, an increase in the infiltration rate increases energy demand. When it is hotter (and/or more humid) outside than inside - more cooling is required. When it is colder outside than inside - more heating is required. Interestingly, there is a modest advantage for cooling in Canberra and West Sydney where the cool-down advantage in the evenings must exceed that keeping cool disadvantage during the heat of the day. Also interestingly, the disadvantage in Darwin is dominated by the latent load (the removal of excess moisture from the humid infiltrating air).

It is also apparent that the infiltration penalty is relatively insensitive to the other thermal enhancements to the house. The big difference between the Bare and the Mid cases is due to the infiltration increment being different (exhaust fan versus weather-stripping) in this study.

Ventilation

For the bulk simulations of these three house types, standard ventilation rates for cross-ventilated houses within the NatHERS software were used. For this sensitivity study, the ventilation rate was doubled in the case of House 5 only (to account for its high set structure and large openable window areas) and the revised simulation results compared with those of the archetype (see Figure 41).

As expected, the increased ventilation rate reduces energy demand in all three climates, especially in the Bare case where poor summer performance in the absence of shading is most marked and most ameliorated. In a few instances, heating energy demand is slightly increased and this is thought to be an effect in the mid seasons when superior cooling early in the evening results in a small demand for heating before midnight on days of high diurnal temperature swing where otherwise no heating would be required at all.

Continuous Occupancy

For the bulk simulations of these three house types, standard occupancy hours within the NatHERS software were used as well as an unoccupied during working hours option. For this sensitivity study, the occupants were assumed to be continuously present and the plant operated continuously (i.e. as the thermostat demanded) and the revised simulation results compared with those of the archetype (see Figure 42)

As expected, the increase in occupancy from 17 hours to 24 per day resulted in very large increases in energy demand in all three climates and house types. The predominance of the effect on heating demand in Canberra is marked, with scant effect on cooling demand due to the extra hours falling in the coolest and mostly sunless part of the diurnal cycle (midnight to 7:00 am). In both Canberra and West Sydney the marked difference between the highly susceptible Bare and the relatively unaffected Mid and Better confirms their financial advantage as even greater in this mode of operation. The much more modest advantage of the thermally enhanced configurations in Darwin is due to the large single glazed window areas whose tinting and improved shading presents no advantage in the night.

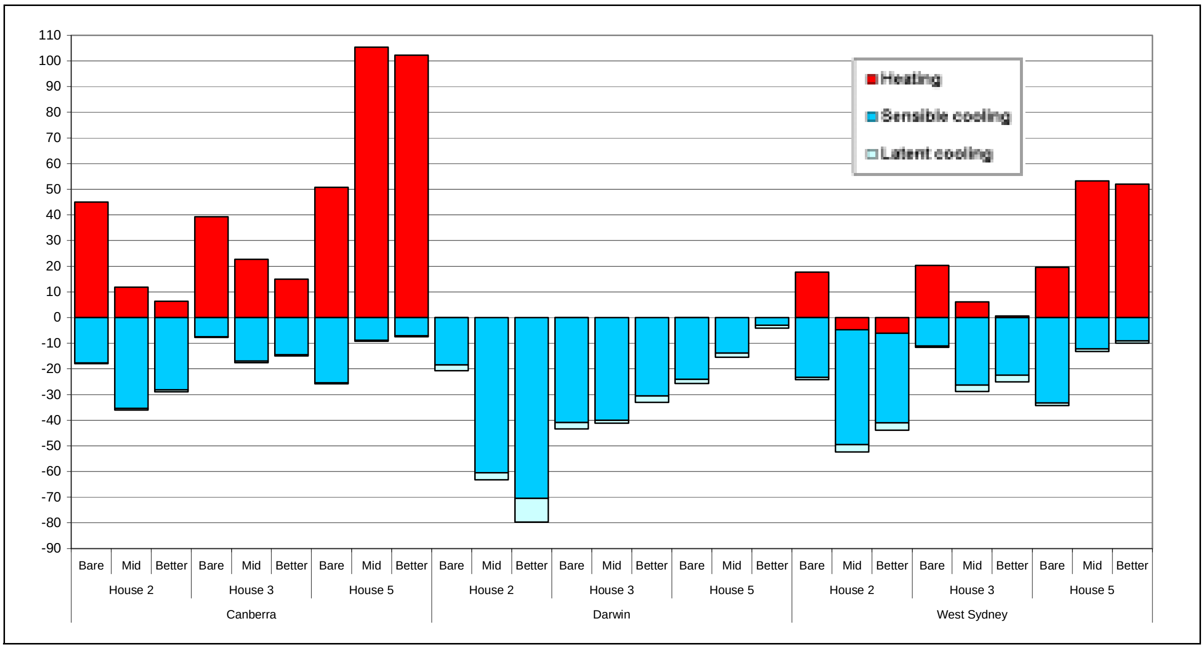

Figure 37: Sensitivity to the absence of carpet (MJ/m²)

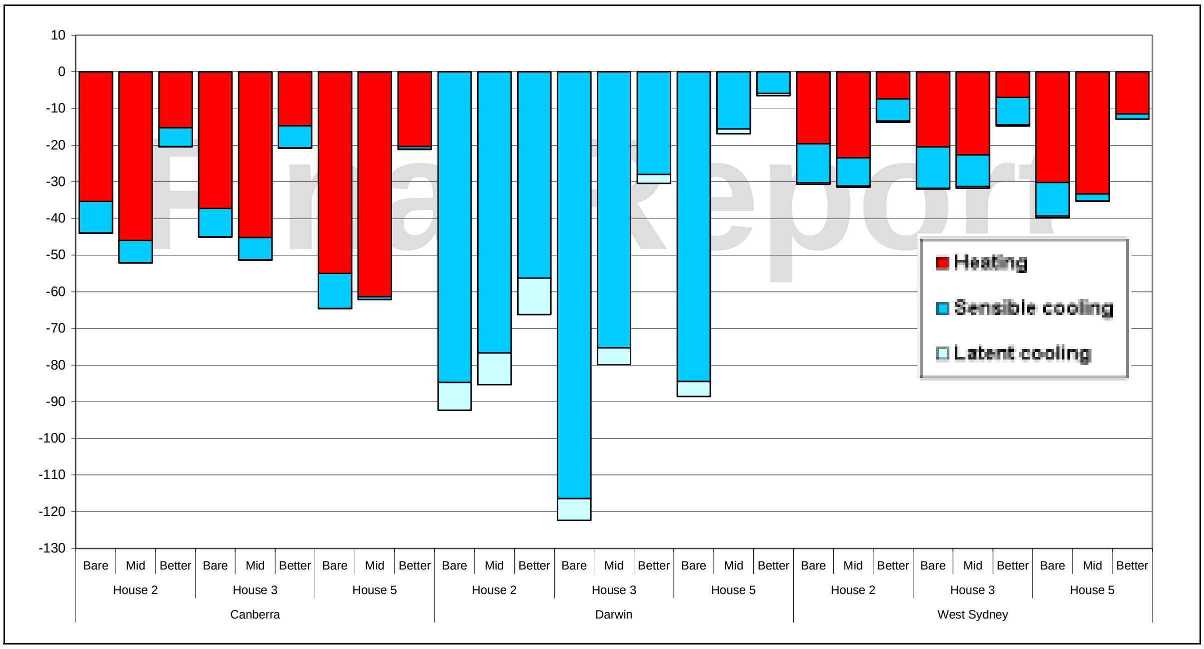

Figure 38: Sensitivity to presence of curtains/blinds (MJ/m²)

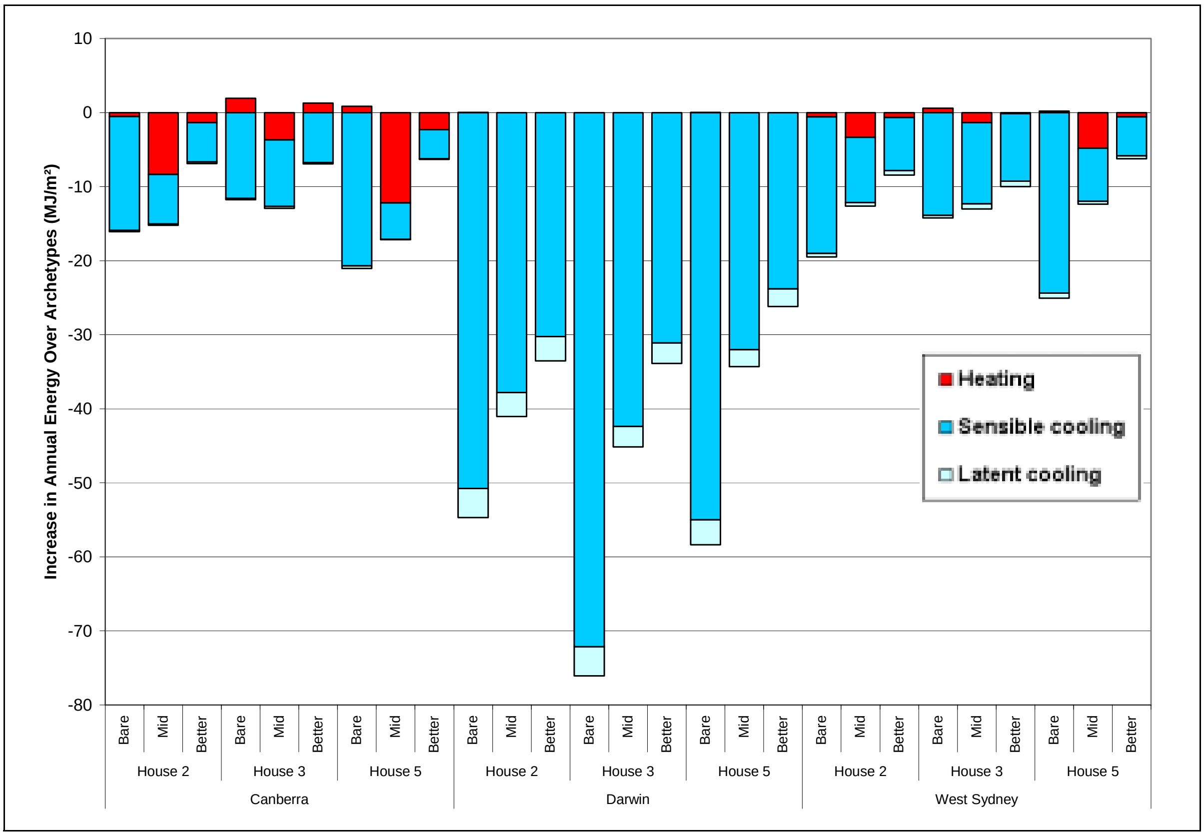

Figure 39: Sensitivity to the reduction of glazing area (MJ/m²)

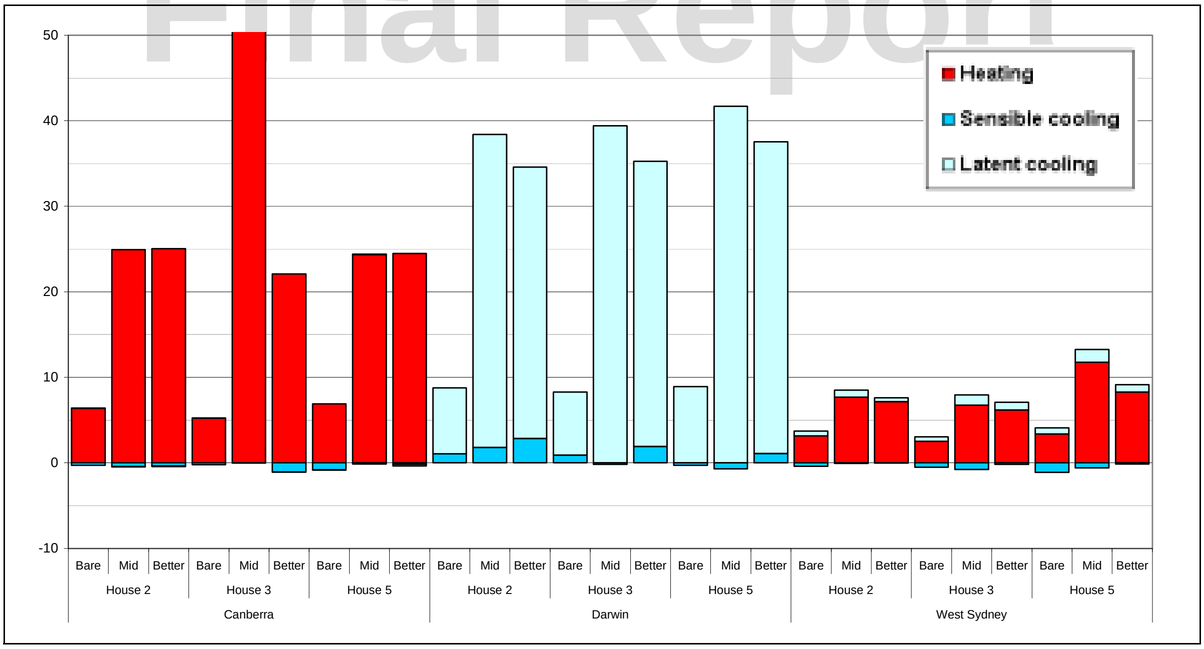

Figure 40: Sensitivity to increase in infiltration (MJ/m²)

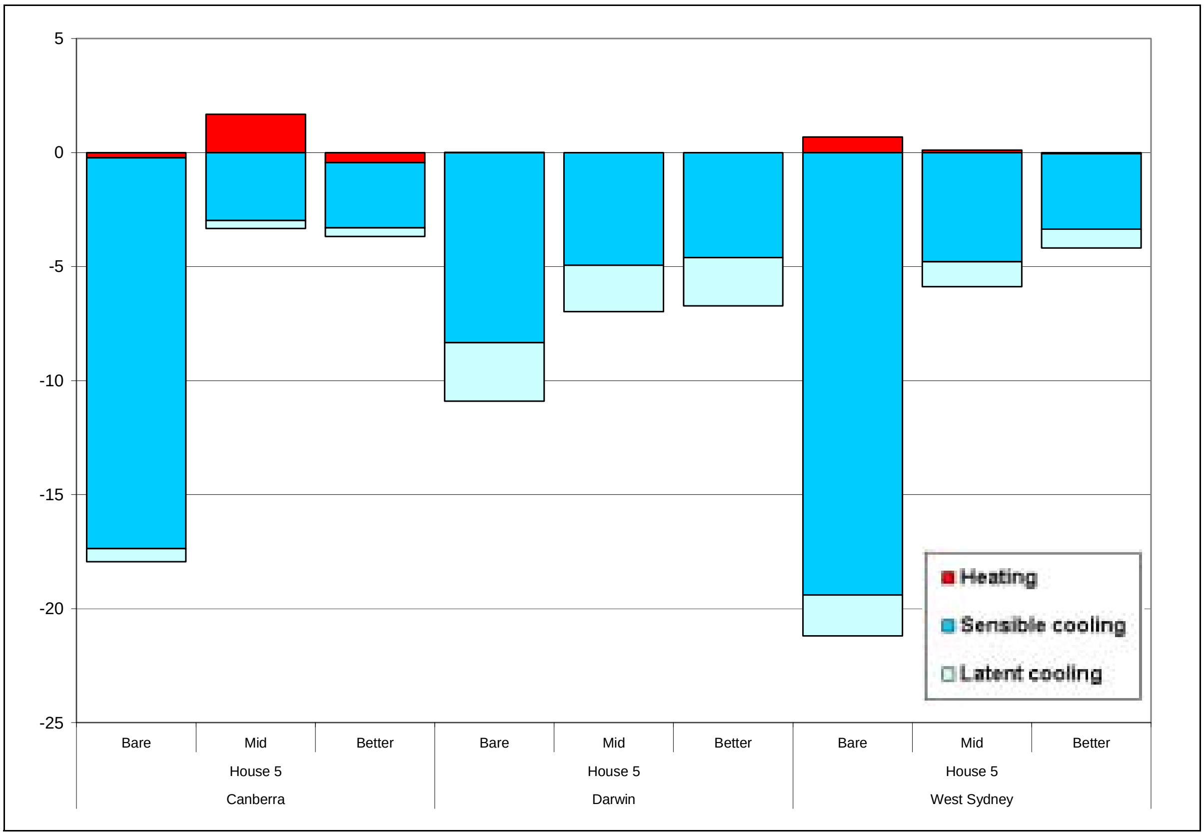

Figure 41: Sensitivity to increase in ventilation (MJ/m²)

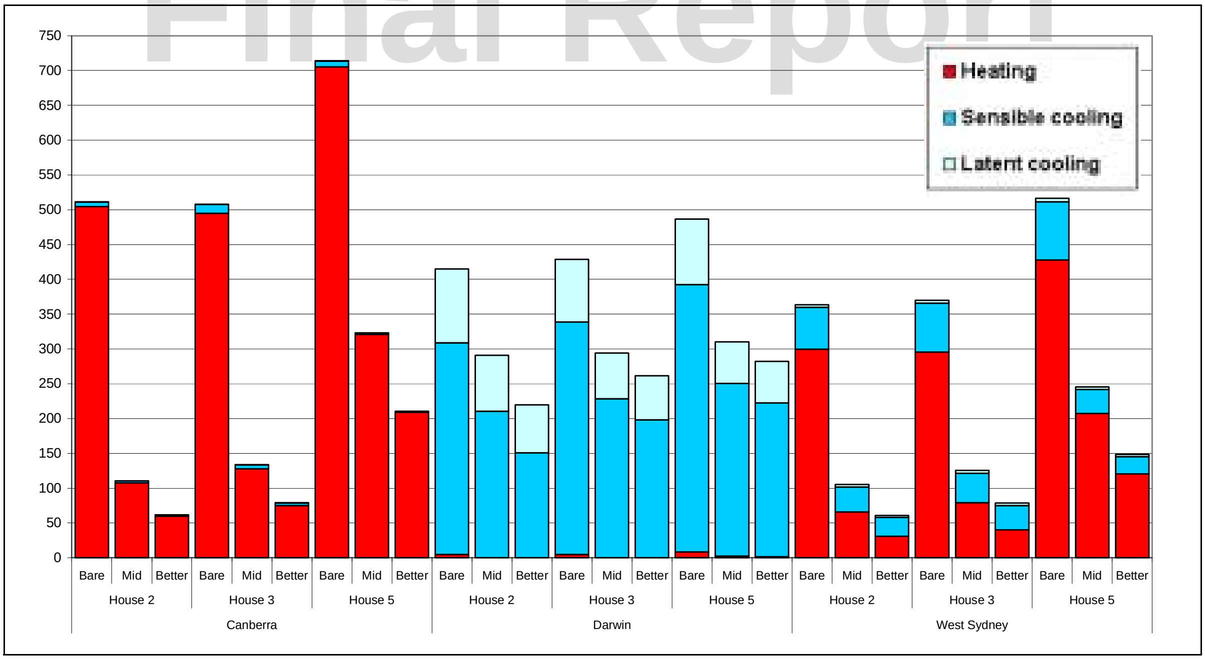

Figure 42: Sensitivity to continuous occupancy (MJ/m²)

6.2.3 Recommended further analysis

The sensitivity studies undertaken here are those judged to be the most important in this context. They are not however exhaustive and further work is recommended to attain the fullest confidence in the results of this cost benefit study overall. Aspects requiring such study include:

- **Thermostat settings:** These are known to be critical in linking dwelling performance with energy demand, particularly with passive solar design in temperate and cool climates (Pears, 1987). The settings in NatHERS are rationally based but are not founded on statistically valid empirical research so some parametric analysis of its importance is indicated. Similarly, in the humid tropics, the temperature differences are small at night so that a 1 °C or 2 °C difference (say from having a ceiling fan on while air-conditioning) could achieve a marked reduction in cooling demand.

- **Surface colour:** Darker colours (higher solar absorptances) will give lower heating and higher cooling demands than the mid colour used for the roof and walls for the bulk runs. The reverse is true for light colours. The poorly insulated elements are particularly susceptible to this affect.

- **Slab edge insulation:** This was estimated in the bulk runs, by modelling the insulation of the slab over the full areas with 20 mm polystyrene foam but only costing 50 mm insulation for 1.0 m around the perimeter. This was due to a limitation in NatHERS and needs to be tested with EnCom2 or another simulation program with a realistic algorithm for heat flows in edge-insulated slabs.

- **Non-cardinal orientations:** In some climates ordinal orientations will be more challenging than the cardinal orientations checked in the bulk runs. This effect should be quantified by a set of re-simulations of the most sensitive design, House 6.

- **Internal appliance loads:** Increasing appliance loads from higher numbers and longer operating times of appliances will reduce the demand for heating and increase the demand for cooling. The reverse is true of reducing appliance loads which may come from increasing efficiency of the appliance stock over time both in operation and on stand-by.

- **Glazing placement:** Performance enhancement can be achieved without added construction costs by the relocation of unchanged total glass areas from the east and west to the south and especially the north in climates needing heating.

- **Glazing types:** Only generic advanced glazings were simulated but the WERS[xx] ratings can be used for much finer differentiation and higher performance materials than used in the generic glazings are commercially available as imports (e.g. argon filled low-e double glazing).

- **Suburban and landscape shading:** The simulation in the bulk runs and in the sensitivity studies above assume negligible shading from plants and surrounding buildings such as an attached carport or the neighbour's home. Evaluation of the impact of common degrees of shading (commonly called solar obstruction in the winter of the cooler climates) that will occur over the life of these new dwellings would enhance the applicability of the study results.

xx Window Energy Rating Scheme operated by the Australasian Window Council.

- **Skylights:** The merits of skylights vary with size, slope, summer shading, glazing characteristics and orientation as attested in the recently launched SERS[xxi] rating scheme and almost always reduce the energy efficiency of the house with regard to heating and cooling. The openable versions can also provide excellent stack effect ventilation for summer evenings. The simulations in this study included no skylights at all.

- **Costing the benefit of daylight:** Variations to glazing type, area and placement (including skylights) have an impact on the daylighting quality of the house and concomitantly on the energy demand for electric lighting. The change in lighting energy demand will often be the reverse of the change in heating and cooling demand adding extra complexity to such an analysis.

- **Eaves widths:** A standard eaves width of 600 mm was used for this study so a comparison of 450 mm vs. 600 mm vs. 900 mm would be required to establish the ideal width for each of the climates.

- **Pergolas and beneficial landscaping:** Much of the summer demerits of poor design with respect to the placement of unprotected windows to the east and west can be ameliorated by beneficial landscaping undertaken by the occupants at negligible cost. Similarly, the addition of pergolas can give summer benefit and when used in cooler climates in conjunction with deciduous vines over large northerly windows can give improved performance in both heating and cooling at quite modest cost. A study of such effects would add to the universal applicability of the results obtained here.

- **Zoning within the house: N**atHERS assumes that the 'Living', 'Sleeping' and 'Other Conditioned' zones (about 90% of the house) are all heated/cooled for the same durations to the same temperature. Conditioning the bedrooms only at night or not at all is a lifestyle that is common in Australia and should be analysed for its effect on energy demand.

- **Sub-floor ventilation rates:** In the case of enclosed timber floors and with open elevated timber floors (with and without insulation) the thermal transfer (usually heat loss) is highly dependent on the sub-floor ventilation rate. The impact this has on the cost effectiveness of underfloor insulations should be analysed.

- **Plant savings by better design/construction:** The thermal analyses in this study account only for annual energy demand but there is also scope for enhanced thermal performance to reduce the peak heating and cooling loads and thereby reduce the plant size and cost required to maintain comfortable conditions. A recent consultants study for SEAV has examined this for Victorian conditions (Energy Efficient Strategies 2001). That work should be extended to all Australian climates to avoid the cost effectiveness results from this study being misleading and arguing for a lesser performance than can be financially justified.

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xxi Skylight Energy Rating Scheme operated by the Australasian Window Council.

7. CONCLUSIONS & RECOMMENDATIONS

This work has developed a financial analysis tool and an associated database of space heating and cooling energy use which can be used to develop energy efficiency alternatives for Building Code of Australia Class 1 buildings.

A range of six houses has been selected, and model in the NatHERS programme for 12 locations around Australia. Each house has been modelled facing each of the four principal compass directions for four wall constructions (weatherboard, brick veneer, cavity brick and concrete block), two floor types (suspended and slab-on-grade) and two lifestyle occupancies. A range of energy efficiency improvements were modelled as applying to the roof, wall, floor, glazing and windows shading both individually and in combination. A total of approximately 4.4 million NatHERS runs were undertaken.

Each energy efficiency alternative was costed, and a location based pricing variation system developed. The pricing data and the results of the NatHERS model runs are available through the Financial Analysis Tool – an MS Excel 2000 spreadsheet with an associated MS Access database.

This report includes a limited number of results from the financial analysis tool. The tool is now available not only for use in the development of any future BCA energy efficiency requirements, but also to permit other interested stakeholders to explore their specific interests.

A number of issues have been raised during the study, and are discussed in greater detail in the relevant sections and summarised briefly in this section.

7.1 Thermal Resistance

It has become standard practice to specify not the overall component R-value, but the required additional thermal insulation to be added. For example, AS 2627.1-1993 "Thermal insulation of dwellings" and in the ACT Additions to the BCA. ACT 5.2.1 (ABCB 1996) refers the addition of minimum levels of thermal insulation material. In both cases the overall component R-value is not explicitly required. For alternative performance based tools to be used, it will be necessary to have a standardised method of determining (whether by measurement or calculation) the overall R-value (for further discussion see Section 4.3).

7.2 Thermal Simulation Programmes

This work has used the NatHERS programme, and its associated thermal simulation engine CHENATH, to evaluate space conditioning energy use. Additional investigations have also been undertaken with the thermal simulation programmes EnCom2 (developed at the University of Adelaide) and DOE2 (developed at Lawrence Berkeley National Laboratory, USA). Although the results were comparable overall, it was found that there were differences in both absolute and marginal energy requirements for specific cases (for further discussion see Section 4.7 and 4.8).

If more than one thermal simulation programme is to be used for the any future BCA energy efficiency requirements it will be necessary to have a formal mechanism to ensure the results are comparable.

In other countries, this issue has been resolved by permitting the use of validated thermal simulation programmes but only in a comparison manner. Thus it is not permitted to compare the results of one programme with another in order to demonstrate code compliance, it is only permitted to compare the results for the modified building from one programme

7.3 Economic Analysis Issues

The results presented in this report, and the associated financial analysis model cannot be considered to cover all aspects that would be expected in a full economic analysis – specifically non-financial costs and benefits.

Most obviously, non-financial benefits include ‘comfort’. What value should society place on the ability of a house to provide comfort without the use of externally purchased energy? Do the occupants of ‘new’ houses – those to which the BCA will be applied – have different requirements compared to the occupants of older houses? ‘Comfort’ may also provide other benefits – most notably the potential for improved occupant health with houses that are cooler in the heat of summer and warmer in the cool of winter.

In addition, the energy efficiency options need not only impact on reduced expenditure on energy. Examples of this would included the energy efficiency option providing a measurable (but non-financial) benefit e.g. if adding eaves reduces solar gains resulting in more comfortable conditions being provided but no expenditure is made on air conditioning, then there are no operational ‘cost’ savings.

There may also be non-energy benefits of energy efficiency options e.g. eaves perform a critical role in maintaining the weather tight performance of a house, but in this analysis it has been assumed all the cost and all the benefit are solely energy related

There is also the issue of other capital cost reductions resulting from a capital investment in energy efficiency. For example a capital cost reduction in energy using appliances e.g. reducing the temperature in an uninsulated house will require a larger appliance than would be the case in an insulated house. A recent SEAV commissioned study found that industry predictions based on a 2 NatHERS Star house were typically 50% too big for the 5 Star houses. In ducted gas heating plant savings of up to $1,000 were identified. These are higher for combined heating and cooling systems. The 5 Star houses also achieve almost air conditioned comfort in Summer with just ceiling fans.

The financial analysis tool will permit many of these issues to be considered, but this has not been undertaken as part of this project. (for further discussion see Section 5.3). These would include consideration of the range of energy efficiency options under at least three perspectives:

- Societal – say over 40 years
- Long-term owner – say over a 25 year borrowing period
- Short-term owner – say over a 10 year occupancy period

7.4 Financial Sensitivity Investigations

A limited number of investigations have been carried out into the sensitivity of the maximised NPV energy efficiency combinations to changes in discount rate, period of analysis, energy price escalation and gas appliance efficiencies. It was found that the results are particularly sensitive to: changes in the period of analysis, although after about 40 years the curve becomes quite flat; gas appliance efficiencies in the cooler climates; and the energy price escalation.

The sensitivity of the NPV to changes in the occupancy hours, glazing and shading costs were also investigated (for further discussion see Section 5.8).

7.5 Thermal Insulation in Tropical Climate

A separate NatHERS based comfort study found that for a given design, thermal enhancements which increase the energy efficiency when the dwelling is air-conditioned will also improve the dwelling's intrinsic comfort when operated without cooling but with ceiling fans available. This suggests that having separate requirements in the BCA for both air-conditioned and free-running houses may be unnecessary (for further discussion see Section 6.1.5).

7.6 Thermal Modelling Sensitivity Studies

The results of additional NatHERS sensitivity studies investigating the importance of glazing area, the use of curtains and blinds, carpet, natural ventilation and infiltration, and occupancy schedule.

It was found that carpet does provide a noticeable energy benefit, although at a higher capital cost that the use of dropped foil. The use of curtains and blinds is also important, but to achieve the energy benefits requires not only the presence of the curtain or blind, but also the correct operation – something that is unlikely to be included in a building energy efficiency code. Reducing the glazing area, in most cases resulted in a reduction in energy demand for both heating and cooling, although the benefits from openable windows on daylighting and cross-ventilation could not be investigated. Increasing occupancy from 17 hours to twenty-fours hours a day resulted in very large increases in energy demand for the three climates and house types investigated.

A range of further sensitivity analysis is suggested, including investigations into the effects of different thermostat settings; exterior surface colours; slab edge insulation; non-cardinal orientation; internal appliance loads; glazing placement and types and the role of the nearby landscape (for further discussion see Section 6.2.3).

It should be noted that as discussed earlier, these energy studies would not be expected to have a major impact on the conclusions of the financial and carbon mission analysis due to the 'flatness' of the financial analysis curves.

8. REFERENCES

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